I. C. 7121 JUNE 1940

UNITED STATES
DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES
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INFORMATION CIRCULAR

MINERALS USED IN WELDING

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BY

OLIVER C. RALSTON AND M. W. VON BERNEWITZ

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

MINERALS USED IN WELDING[1]

By Oliver C. Ralston[2] and M. W. von Bernewitz[3]

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PURPOSE OF THIS REPORT

The minerals that enter welding-rod coatings and fluxes are the main subject of this report. Few mineral producers know just what minerals and what grades and quantities of minerals are required by the welding trade, and it is for their information that this report has been prepared. The various methods of welding are discussed extensively enough to inform this type of audience. Specialists in welding probably will find little on welding that is of value to them, but they may learn something more about the minerals or mineral products that they use. The authors did not find it easy to prepare this publication, and any needed corrections will be welcomed.

Regarding welding research, Jenks[4/] points out that while the process of welding is simple in operation, the phenomena attending its use are extremely complicated, and the efficient and safe use of welding requires an understanding thereof. Although the fluxes and the coatings used have solved many problems, many other problems require the joint effort of the whole industry; therefore, it is hoped that this report will be found of practical value.

In its annual review of welding, the magazine Steel (January 1, 1940) says that better metallurgical and manufacturing control has improved a wide variety of fastening devices. The increasing use of various types of coated metals requires development of welding techniques and materials for efficient welded structures.

Welding equipment and an experienced welder are necessary at any sizable mining and metallurgical operation, placering of any type, deep mining, ore-dressing, and smelting, especially if the property is somewhat isolated. Broken machinery parts may be repaired quickly, strongly, and cheaply instead of having to wait for spares or new pieces. Any mine with a daily ore output of 100 tons can afford a welding outfit and employ a mechanic with welding knowledge. Bottled gases or suitable electric current is generally available for welding.

Coated electrodes are used in electric welding and bare rods with fluxes in gas welding. Blue goggles always are worn by welders. The lenses protect the eyes from harmful rays and from flying sparks. Many welders wear other protective clothing including gloves and helmets with inserted windows. Welding is done in normal, overhead, and vertical positions, and small jobs can be done in two- or four-sided booths or screens or on a table.

During the symposium on the welding of iron and steel held by the Iron and Steel Institute, London, in 1935, and mentioned later, the Director of Naval Construction said:

4/ Jenks, G. F., Welding Research, Particularly Industrial Research: Am. Soc. Test. Mat. Bull., December 1939, pp. 23-25.

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The past few years have seen the output of a mass of information on all aspects of welding. It is, in fact, difficult to keep pace with all the literature which is being published, and it is still more difficult to extract what is valuable information.

ACKNOWLEDGMENTS

Thanks are due the firms mentioned in the report for information on coating materials. The first draft of this manuscript was read by L. G. Bliss, sales engineer, Foote Mineral Co., and by Paul Tyler, chief engineer Nonmetals Division, Economics and Statistics Branch, Bureau of Mines, and their suggestions have been incorporated. C. M. Davis, mechanic, and M. R. Price, machinist's helper, Eastern Experiment Station, Bureau of Mines, were helpful in supplying information and practice on welding. The Bazzuro Engineering Co. welding shop in Washington, where large and small jobs are done, was visited.

WHAT IS WELDING?

The reviewer of a new book on welding in The Engineer, London, for November 24, 1939, stated that the art of welding is as old as the art of the blacksmith, but it really goes back to early in the 19th century. The American Welding Society defines welding as:

> The localized intimate union of metal parts in the plastic or plastic and molten states with the application of mechanical pressure or blows (as by a hydraulic press or steam hammer), and in the molten state without the application of mechanical pressure or blows (as by hand welding).

Coated electrodes or filler rods and fluxes are used in the second method, all melted by electricity or by oxy-acetylene or oxy-hydrogen jets. These are fusion welding - arc or torch. The proper selection of welding rods is important.

Apparently, judging by advertisements in telephone books, most welding firms are prepared to do either electric or gas welding.

Electric Welding

In arc welding, according to the Procedure Handbook of Arc Welding[5/], the pieces of metal to be welded are brought to the proper welding temperature at point of contact by the heat liberated at the arc terminals and in the arc stream, so that the metals are completely fused into each other, forming a single homogeneous mass after it solidifies. A small pool of metal is formed, and additional metal required is obtained from the electrode, if

5/ Lincoln Electric Co., Procedure Handbook of Arc Welding - Design and Practice: 5th ed., 1938, pp/ 6-7, 21-22.

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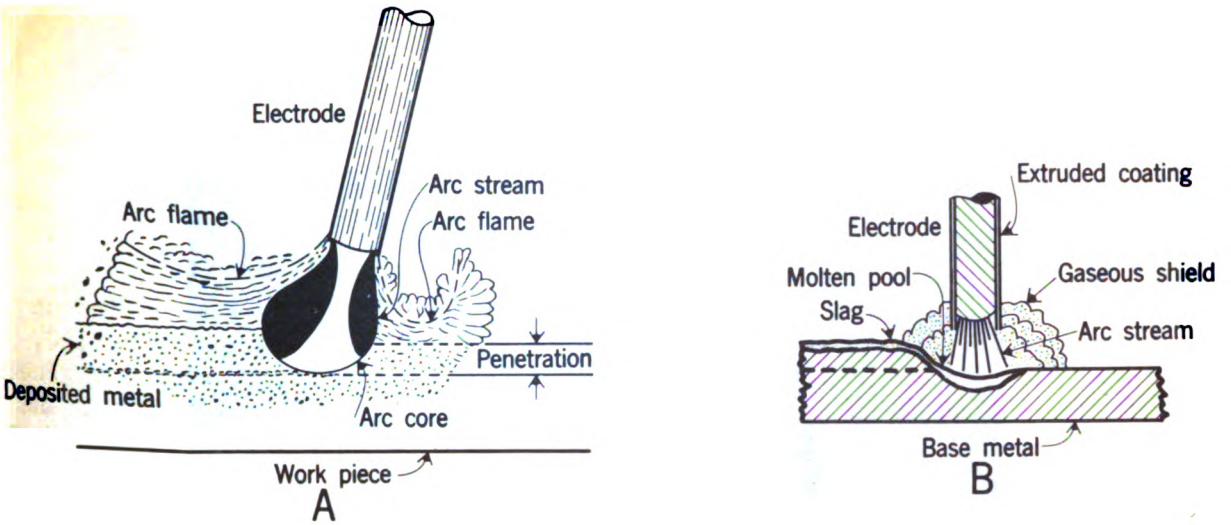

Figure 1.–Electric-arc welding. A, Welding with bare electrode; B, welding with shielded electrode. (Metals Handbook, 1939.)

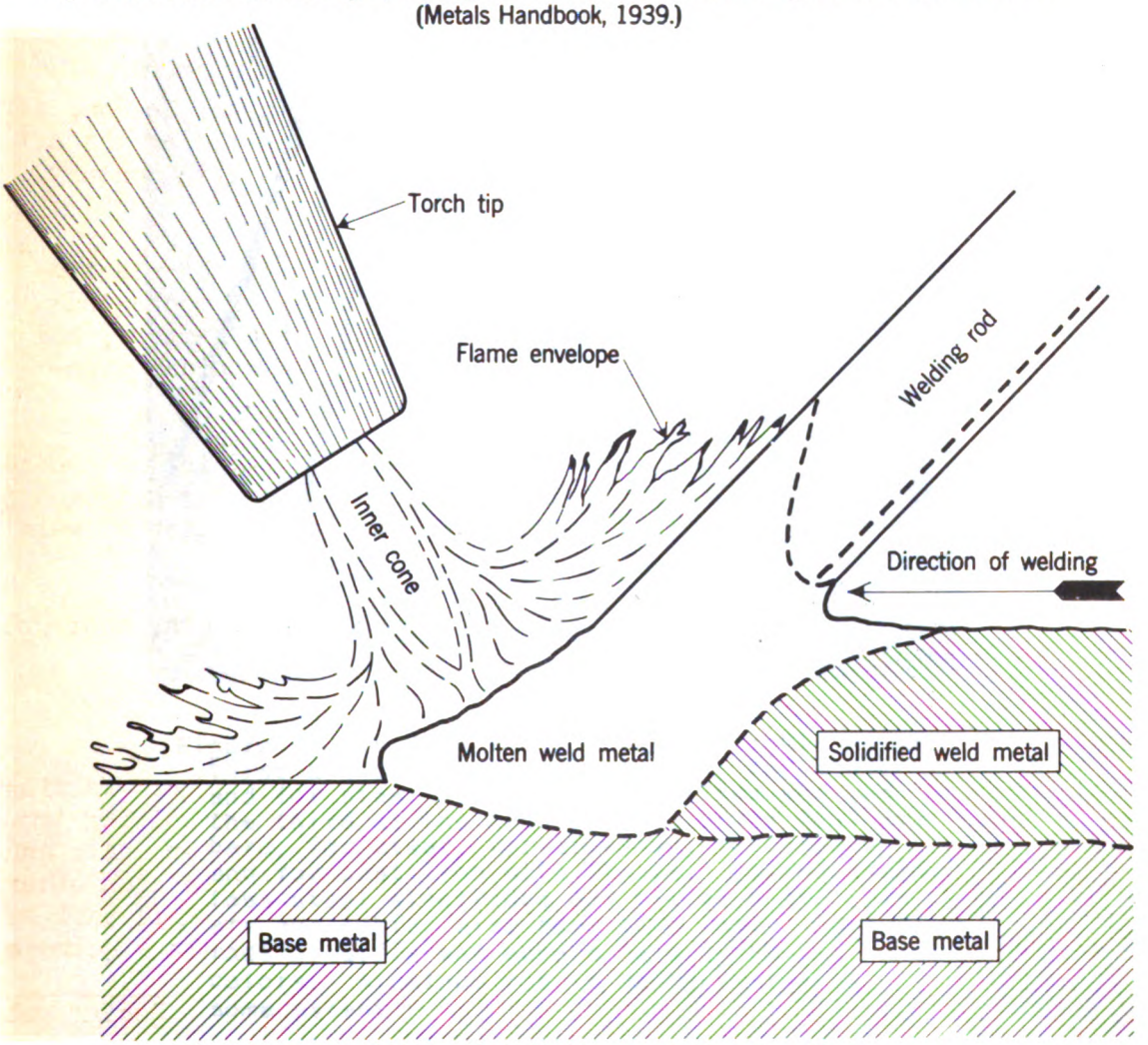

Figure 2.–Gas welding with oxy-acetylene. (Metals Handbook, 1939.)

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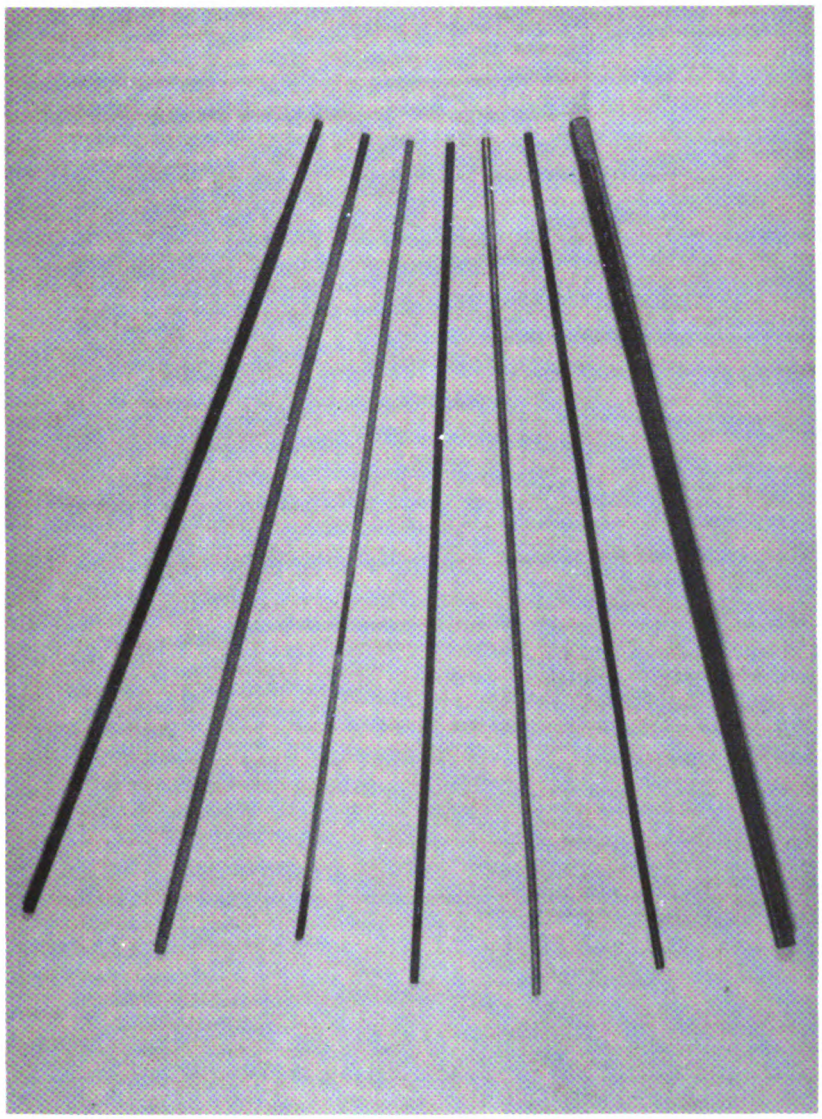

Figure 3.- Welding rods. Left to right: First three are coated, for cast iron, for steel, and for steel (two are held at the end and the third at the middle); the other four are bare, for steel, for aluminum, for bronze, and for cast iron with fluxes. Coated stainless-steel electrodes and nickel-steel rods are available, also some bare rods. Coated rods of different makers have different colors. Aluminum rod is being coated to some extent.

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a metallic electrode is used, or by a filler rod, if either a metallic or carbon electrode is used. Figure 1, A and B, shows, respectively, welding by the ordinary electric arc and by the shielded arc.

An electric arc is nothing more than a sustained spark between two terminals or electrodes. In arc welding the arc is formed between the work to be welded and an electrode held in a suitable holder. The instant the arc is formed, the temperature of the work at the point of welding and the welding electrode jumps from normal to about 6,500° F.

In the ordinary arc, the molten globules that pass from the electrode to the work are exposed to the surrounding atmosphere, which is chiefly oxygen and nitrogen. The molten base metal also is exposed to these gases and they form oxides and nitrides in the weld metal. If during the fusion process the metal is completely protected from contact with the atmosphere, the injurious chemical combination cannot take place. This can be achieved by shielding the arc completely. In manual welding, this is done by using special electrodes that are heavily coated. The coating is of such composition that in the heat of the arc it gives off large quantities of gas, which envelops and completely shields the arc from the surrounding atmosphere. The coating is consumed at a slower rate than the rate of deposition of the electrode metal; as a result, the coating extends beyond the metal case of the electrode and directs and concentrates the arc stream. (See fig. 1, B.) Welds made with a shielded arc are stronger and more ductile than ordinary welds.

In automatic welding with the shielded carbon arc, a substance known as an autogenizer is added as paste, fibrous cord, or powder. Sometimes the paste and fibrous forms are used together.

Gas Welding

In gas welding, according to Metals Handbook, 1939[6/], the heat is supplied by the combustion of a fuel gas with atmospheric or pure oxygen. These are mixed in a torch and regulated to produce an impinging flame. The gases most commonly used are oxygen and acetylene (see fig. 2), although hydrogen and other combustible gases are used to some extent.

As a rule, in fusion welding with oxy-acetylene, a filler metal is added in the form of welding rod to form the welded joint. As a means of floating out impurities or aiding in obtaining a satisfactory bond, flux is employed in welding some metals, such as cast iron, certain alloy steels, and the nonferrous metals. (See fig. 3.)

Soldering

Soldering is mentioned in this circular. It closely approximates fusion welding, although some confusion exists regarding the terms. The Soldering Committee of the German Association for the Science of Metals defines it as follows:

6/ American Society for Metals, Welding of Metals: Metals Handbook, 1939, pp. 220-259.

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Soldering or brazing is the joining or building up of heated metals and alloys, which stay in the solid state, by means of a molten junction medium.

In soldering, some of the solder enters the base material, but the strength of the joint is merely that of the soldering metal.

In fusion welding, the base material and the filler material, from coated rods or from bare filler rods with fluxes, all melt and fuse with one another.

There is "soft soldering" such as when only the solder between the metal parts to be joined is heated and the metal parts are not; and "hard soldering," as when the metal parts to be joined are heated and the solder is melted, as in silver soldering. Barber[7] (Kester Solder Co., Chicago) defines a soldering flux as some agent that promotes or accelerates the wetting of a metal by molten solder. Soldering involves an alloy action between bare metals, and it is the function of the flux to insure a complete metallic contact. Following is a classification of fluxes for soft soldering:

1. The salt type, such as the chloride of zinc, ammonia, calcium, magnesium, and aluminum. Solutions of one or more of these salts are popularly known as acids.

2. The carboxylic acid type, such as stearic, oleic, palmitic, benzoic, tartaric, furoic, phthalic, and similar organic acids; these are often popularly classified as waxes.

3. The weak organic base type, such as aniline, urea, ethylene diamine, acetamide, and certain other amines and amides.

4. Rosin.

Barber concludes that:

The theory of flux action which best fits the facts is that the fluxing agent, depending on its activity, first penetrates the oxide film and attacks the raw metal, liberating small amounts of hydrogen or reducing vapors which prevent further oxidation as long as oxidizing agents are not present in the flux itself; this attack, in conjunction with the reducing agent, serves further to loosen the remaining oxide film until, being wetted by the flux, it is finally coagulated and floated off into the main body of the flux. It is unlikely that the flux dissolves much of the oxide; it is more probable that the flux wets, suspends, and coagulates the oxide loosened by a penetrating and reducing action.

7/ Barber, Clifford L., Soft Solder Fluxes - Practice and Theory: Ind. and Eng. Chem., vol. 29, October 1937, pp. 1114-1117.

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Zinc is commonly soldered. German Patent 676,495 (1939) covers a suitable flux consisting of 65 percent ammonium chloride (sal ammoniac), 25 percent zinc chloride, 4 percent sodium chloride, and 3 percent each lithium chloride and potassium fluoride.

RODS OR ELECTRODES AND COATINGS

Electrodes

Electrodes are available for all types of welding, including different metals. (See fig. 3.) They may be either of metal or carbon, depending on the job. In manual welding, the metallic electrode generally is used. They range in size from 1/16 to 3/8 inch in diameter and 14 to 18 inches in length. The proper size also depends on the class of work to be done. "Washed electrodes" are coated lightly with an arc-stabilizing chemical such as lime. "Semicoated electrodes" have a coating which generally is applied by dipping and which constitutes 1 to 2 percent of the total weight of the electrode. Such a coating stabilizes the arc and may partly control oxidation of the molten metal, as it is deposited by forming a thin film of slag over the surface of the bead. "Heavily coated shielded-arc-type electrodes" utilize all the benefits of chemical coatings. These may constitute a tenth of more of the total weight of the electrode, and they control the arc characteristics and the physical and chemical properties of the deposited metal. "Carbon electrodes" for manual welding and cutting are made in sizes 5/32 to 1 inch in diameter and 12 inches in length. For automatic welding with the shielded arc, the electrodes are 3/16 to 1/2-inch size. Carbon-arc welding differs considerably from metallic-arc welding in that the heat is used only to melt or fuse the base metal. Filler metal is not commonly used.

Electrodes are held by a light spring clamp or other device provided with a handle for the welder and through which the power wire passes.

Minerals used as stabilizers include titanium oxide (this enables a longer arc to be maintained), iron oxides, manganese oxide, lime, sodium and potassium minerals or compounds, and thorium oxide. They lessen wandering of the arc at the tip of the electrode. The stability of an arc of given length is the ratio of the distance the arc can be lengthened before being extinguished to the given arc length. Stability often includes smoothness and minimum sputter. Voltage and other factors affect arc stability. Steel deoxidized with aluminum is bad for a steady arc. Alkali compounds, especially those containing sodium and potassium, have a marked stabilizing effect on the arc, but the former accelerates and the latter retards the flow of metal. Calcium compounds steady the arc, as does iron oxide. Iron silicates vary in effect.

Coatings

Mathias[8/] (Research Laboratories, Westinghouse Electric & Manufacturing Co., East Pittsburgh) concludes that:

8/ Mathias, D. L., Fluxes - Their Function in Metallic Arc Welding: Foote-Prints, vol. 9, December 1936, pp. 1-12.

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The subject of electrode fluxes [or coatings] is extremely complex and involves a knowledge of metallurgy, chemistry, ceramics, and circuit characteristics.

Flux compositions are usually guarded with considerable secrecy. Fundamentally, they consist of acid, basic and/or neutral slag-forming materials, arc stabilizers, de-oxidizers and/or alloying materials, organic material if desired, and a solution of soluble silicate for a binder. No sharp distinction can be drawn as to the function of any single ingredient of a flux, for each material directly or indirectly influences one or more of the functions of the composite flux. Silica, manganese dioxide, iron oxide, amphibole, feldspar, and titanium oxide or rutile may be considered as slag-forming materials, while ferromanganese, ferrosilicon, and silicomanganese usually function in a dual capacity as deoxidizer and for alloying additions. Sodium silicate is almost universally used as a binder.

Coatings are really fluxes or reaction substances added to the outside of rods or electrodes to stabilize and protect the arc and to provide a method of depositing fluxes on the welds and form slag which is easier than dipping bare rods into a container of flux and thus carry it to the point of welding. Coatings affect the ease with which the arc may be maintained and the character of the deposited metal. They modify the rate of fusion and depth of penetration. Also, certain treatment before application of the coating material facilitates adhesion of the coating and improves its effects (to cite a patent).

Coatings are said to take 1.2 kilowatt-hours per pound of metal deposited compared with 0.86 kilowatt-hour for bare rods.

Quantity of Rods and Coatings Made

Of the 28,500 tons of welding rod sold in 1934, about 15,000 tons were coated wire that required 2,000 tons of coating materials, according to Bliss (Foote Mineral Co.), cited later.

Arcrods Corporation, which has plants at Sparrows Point, Md., and at Cuyahoga Heights, Ohio, and makes the General Electric electrode and whose coating formulas are kept secret, through F. Pruyn, Jr., assistant vice-president, gave the Bureau of Mines the following information:

During the year 1939 there were approximately 120,000,000 pounds of heavy-coated electrodes sold by about 20 concerns. They sold also substantial quantities of light-coated electrodes, which I will presume to neglect from the mineral-consumption point of view.

On the average, it might be estimated that the heavy-coated electrode has a mineral coating of about 15 percent of its total weight, and that due to manufacturing wastes and drying losses, the mineral requirements are somewhat in excess of 20 percent.

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There is a number of basically different types of coatings made by each manufacturer, and there is a substantial variation between these basic types. Coating ingredients of major importance are rutile, titanium dioxide, cellulose flock, ferromanganese, asbestos, iron oxide, sodium-silicate solution, feldspar, ilmenite, silica, calcium carbonate, fluorspar, clays.

Gas-welding wire, arc-welding wire of low carbon content, special annealed low-carbon electric-welding wire supplied in coils, a standard high carbon grade and a special high-carbon grade electric-welding wire, and a special high-manganese steel electrode are made by John A. Roebling's Sons Co. All are either normally uncoated or have a light coating. The other rods are packed in standard lengths, each package holding 50 pounds.

Manufacture of Coated Rods

The making of coated rods has not received much publicity. A well-known maker of electrodes stated recently (letter to the authors, December 1939) that

> The information on our coated rods which we send out concerns what the rods will do and not what the coating is. This, I think you will find, is a secret with all manufacturers.

(This last statement is true, although some will give the ingredients but not the quantities, but the patents issued reveal these to some extent.)

The invention of United States Patent 1,936,693 (1933), issued to Richard Stresau and assigned to A. O. Smith Corporation, resides in mixing a lubricant material such as kaolin (9.4 percent by weight) or silica flour (4.7 percent by weight) with the other ingredients - wood flour, 15.3 percent by weight, and sodium silicate of 42° B. (70.6 percent) - whereby the application of the covering to the rod is greatly facilitated and a weldrod having improved welding characteristics is produced. The method of applying the mixture to the rod is shown and consists of a pair of rollers, which feed the rod through a chamber in which the mixture is held under pressure, and a nozzle, through which the rod and coating thereon are discharged. This operation is continuous. Then the rods are baked or dried suitably.

United States Patent 1,936,349 (November 21, 1933, Alfred C. Castle, assignor to A. M. Castle Co.) covers a process for coating rods with trisodium phosphate, powdered magnesia, calcium carbonate, zinc oxide (this may be omitted), and common borax or borax glass by placing the rods in a tumbling mill and allowing the pulped and heated (130° to 140° F.) mix to be impressed upon the rods. Two heavy rods or bars also are placed in the mill to assist in this operation.

Under United States Patent 1,940,573 (December 19, 1933, J. B. Austin, assignor to Una Welding Inc.) depressions are first formed in the surface of metal rods of any composition, ferrous or nonferrous, and the fluxing material and binder, in the form of a paste, is preferably applied during the operation of drawing to final size.

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By means of what appears to be an intricate machine, C. J. Kotchi (U. S. Patent 1,976,026, October 4, 1934, assignor Una Welding Inc.) forms cavities or recesses in the rod, passes the rod through the flux, and then scrapes off the surplus flux.

Investigations on Electrodes and Coatings

Bliss. - Bliss[9/] (Foote Mineral Co.) has thoroughly investigated welding-rod coverings or coatings, the materials used, their physical effects upon the finished rod, and possible remedies for some of the difficulties experienced in applying the coating to the rod. He says that in electric arc welding the metal electrode is rapidly gaining favor, and the advantages to be obtained by the use of coated rods have long been recognized. Probably the greatest use for welding lies in the field of structural steel, which means that coated rod or wire will of necessity be in increasing demand. Other excerpts from Bliss's paper follow:

> The general practicd has been to select electrodes whose composition is the same as the base metal to be welded, and while this is a good rule to follow in many cases, there are important factors to consider, in electric arc welding in particular, which indicate that a divergence from the rule would be desirable.

(For instance, there are losses of carbon, manganese, nitrogen, and other elements in the rods by volatilization or by slagging, and to obtain a weld of similar composition as the base metal, these losses must be compensated.)

> There are many methods employed to prevent volatilization losses, but the most popular is the application of various coverings to the rod, as in that case other advantages are also obtained. The compositions of the coatings are as numerous as the number of types of welding rods on the market, but in general they are usually composed of a binder, a ferro-alloy, a flux, an arc stabilizer, and occasionally a fibrous material such as asbestos (although it is fast losing favor to cotton fiber or some other cellulose material), added to produce a lighter slag and reinforce the coating. The character and proportions of these materials vary with the purpose for which the rod is intended and with each individual's convictions.
>
> The usual methods of producing heavily coated rods are by dipping, extrusion, or some modification of extrusion.

(Coatings are made up in the form of a fairly viscous suspension of metallics or nonmetallics. The rods are dipped therein, drained, redipped, and the process repeated until the coating is the desired thickness. The formation of bubbles (gassing) from carbides is troublesome; so are the peeling and cracking of the coating; but tests on particle size and reactions of [reduction by] ferro-manganese have resulted in the use of a non-gassing grade.)

9/ Bliss, L. G., Welding Rod Coatings: Welding, vol. 5, May and June 1934, pp. 204-206, 208, 242-243, 255.

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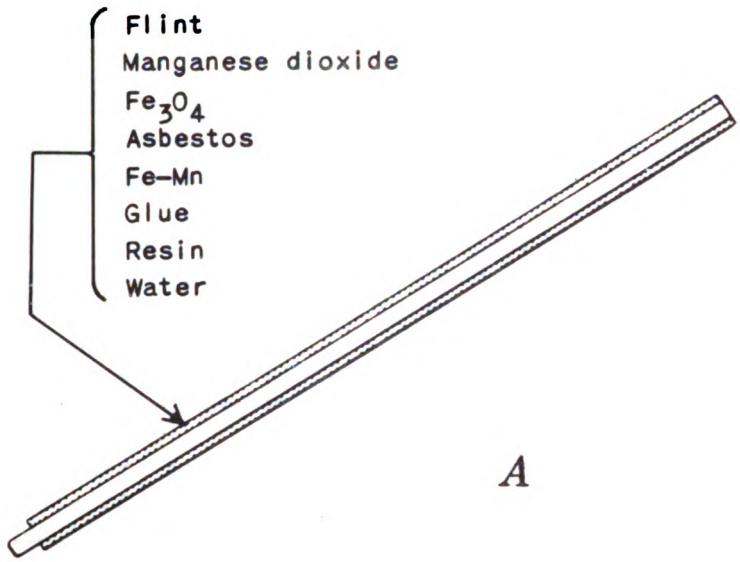

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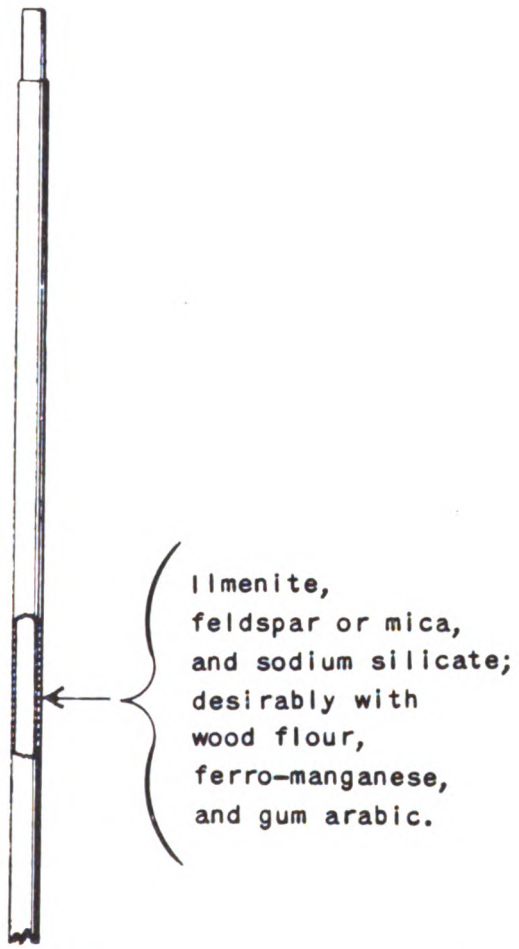

Figure 4.– How welding rod patents are shown. A, No. 2,107,434; B, No. 2,032,322 (lower part cut off).

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Sputtering in welding is a problem for the manufacturer of the rod. Even when the rod is apparently of uniform coating, sputtering will sometimes occur. Such a tendency may be diminished appreciably by the addition of titanium compounds to the coating formula.

Titanalba, a pure white titanium dioxide, rutile, containing about 94 percent TiO_2, cerium rare-earth hydrates, and ferrotitanium all have been used to some extent as arc stabilizers.

(A little fluorspar, calcium fluoride, has been used with titanalba, but the fluorine liberated is irritating and dangerous to the operator.)

Although there are a few coated rods that feature a nonslag deposit and at the same time give welds of greater tensile strength than those which have a protective slag, it is still generally assumed that a slag has several definite functions, important among which are protection from formation of oxides and nitrides, and formation of a vehicle for the removal of detrimental impurities.

(Titanium compounds, amphibole or asbestoslike mineral, cotton or other cellulosic material, and manganese dioxide are widely used in coatings.)

(Bliss also gives briefs of 51 selected patents on welding rods, coatings, and fluxes in the United States and in some foreign countries during a period of 6 years.)

Figure 4, A and B, is from the Official Gazette of the United States Patent Office and reveals how weldrod patents are shown.

Notvest. - Although we are not directly concerned in this report with the metallurgical characteristics of drawn wire for arc-welding electrodes, Notvest's lengthy investigation and paper[10] shows that the requirements for wire for this purpose are entirely different from all other wire requirements because of superheating of the metal and its quick freezing when utilized as arc-welding electrodes. Notvest explains and illustrates what goes on during welding by means of oscillograms and by photographs at the point of the electrode. The former reveal the number of short circuits or drops of molten metal that have passed across the arc gap, analyses of the electrodes, voltages, and amperages. The chemical reactions that take place are given, as well as the details of 22 experiments on different sizes and analyses of wire at various temperatures with the current resistance. Notvest states that most of the gas-shielded electrodes sold in the United States "are copies or slight improvements upon United States Patent No. 1,301,331 1919 , issued to R. S. Smith, and United States Patent No. 1,754,063 1930 issued to Richard Stresau, ***."

10/ Notvest, R., Steel for Arc-welding Electrodes: Wire and Wire Products, vol. 11, 1936, pp. 527-551. (For this contribution, Notvest received the Wire Association medal in 1936. Several patents have been granted him.)

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Titanium Minerals

In discussing the use of titanium minerals in welding rods, Bliss[11/] states that titanium dioxide, up to 56 percent of the coating, is used, but the 98-percent grade is expensive and a cheaper substitute has been desired Rutile of 95.7 percent TiO_2 content, now used almost exclusively, has merited considerable attention. The phosphorus and sulfur content should not exceed 0.03 percent and 0.01 percent, respectively, and the mineral fineness 90 percent through 325 mesh. However, a balanced particle size is necessary to prevent cracking in drying; therefore, coarse grinding sometimes is advantageous. An ilmenite of 58 percent TiO_2 and 35 percent FeO content would be an economical source of titanium; also "ticasil," a calcium-titanium-silicate with 36 percent TiO_2, 30 percent SiO_2, and 28 percent CaO. Titanite or sphene is a natural calcium-titanium silicate of this analysis.

Bliss concludes that rutile, ilmenite, or "ticasil" cannot always be substituted for pure titanium oxide because some coatings demand an arc stabilizer of a firmness attainable only by the precipitated material, analyzing 98.8 percent TiO_2, 0.03 percent Fe, and 0.041 percent S.

Problem suggested. - J. F. Lincoln, president of The Lincoln Electric Co., a manufacturer of electrodes and welding equipment, wrote the Bureau of Mines in December 1939 that there is a real problem in getting titanium dioxide in the form of rutile without impurities.

Probably iron minerals are among these and low iron is desired. Crushing, tabling, and magnetic separation are applied to rutile and ilmenite-bearing ores.

United States Patent 2,060,681 (1936), issued to Virdis Miller and Joseph H. Humberstone and assigned to the General Electric Co., says that

> The presence of ilmenite in substantial percentages causes the flux material to form a slag, which is characterized by its ability to cover the weld metal. Due to its presence, the surface of the weld metal also becomes smooth and of good appearance.

Titanium, as rutile, 90 percent or more titanium oxide, occurs in gneiss, schist, quartzite, granular limestone and dolomite, and in sands from crystalline rocks; and as ilmenite, an iron-titanium oxide with 52 percent TiO_2, in crystalline rocks and sands therefrom.

As noted elsewhere, the Foote Mineral Co. two grades of air-floated rutile contain 2.2 and 1.12 percent iron; and titanalba, 0.03 percent iron, also 98.8 percent TiO_2. Welding-grade ilmenite carries about 24 percent iron as 12.29 percent ferrous oxide and 24.59 percent ferric oxide.

The need of both welding-supply dealers and of the titanium-pigment manufacturers for obtaining inexpensive low-iron titanium dioxide is probably satisfied by recently patented processes for removing iron from

11/ Bliss, L. G., Titanium Minerals in Welding Rod Coatings: Foote-Prints, vol. 8, June 1935, pp. 10-15.

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titanium minerals too high in iron to be satisfactory, such as those of J. E. Booge (E. I. duPont de Nemours & Co.) in the United States Patent 2,183,365, and of I. E. Muskat and R. H. Taylor (Pittsburgh Plate Glass Co.) in 2,184,884-5-7. All of these are selective chlorination processes for removing most of the iron and leaving most of the titanium oxide behind.

Manganese Minerals

Two common ingredients used in coating welding rods are artificial or natural manganese carbonate (rhodochrosite), and manganese dioxide (pyrolusite). They produce a brittle, fluid slag, and replace the manganese that is volatilized in the arc. Ferromanganese acts similarly.

Enck[12/] (Foote Mineral Co.) discusses the effect of manganese in rutile-type electrodes. Ferromanganese is used in mild-steel coatings for deoxidizing and removing gases in the weld, also for control of interfacial tension between slag and weld metal. Tests were run on high (6.9 percent) and medium (1.19 percent) carbon ferromanganese as well as on bare rods of 0.51 percent Mn and 0.14 percent C and 0.15 percent Mn and 0.06 percent C. The coating mixture consisted of rutile, cellulose, clay, asbestos, sodium silicate, and ferromanganese. Potassium silicate was substituted for sodium silicate in some tests; also manganox (prepared hausmanite, Mn_3O_4) and manganese carbonate, $MnCO_3$. It was found that:

> Increasing the amounts of ferromanganese in a coating results in an increase of manganese in the weld metal but has very little effect on the carbon and silicon contents.
>
> * * * Manganese seems to have a marked effect on the surface tension of the slag and the interfacial tension of the slag and weld metal.*** By increasing the organic content or by the addition of a certain percentage of potassium silicate, a weld metal of higher manganese content can be produced by using a smaller percentage of ferromanganese. Nevertheless, the same general results would apply on any modifications of the Foote basic formula.
>
> The partial substitution of other manganese compounds for ferromanganese can be accomplished with little effect on the requisite chemical properties of the weld metal.

Manganese occurs as black-brown oxides, soft and powdery to hard lumps or nodules, with more or less iron and silica, in residual clays, shales, sandstone, and quartzite; as replacements in limestone; in quartz; in sands; in volcanic tuffs and flows; in rhyolite; and as the pink carbonate, alone or associated with rhodonite (Manganese silicate), in veins of silver and zinc.

12/ Enck, Ernest G., Manganese in Rutile-Type Coated-Steel Electrodes: Foote-Prints, vol. 12, June 1939, pp. 26-35.

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Feldspar

Feldspar, a silicate of alumina with potash, soda, or lime, is used in some coatings, as will be noted in this report. The mineral occurs in most igneous rocks, especially in pegmatite or giant granite, associated with quartz and mica. It is fluxing in nature and helps build a slag of desired characteristics.

Cryolite

United States Patent 2,141,929 (1938) issued to M. R. Moritz and I. C. Fitch and assigned to General Electric Co., relates to the use of cryolite (a fluoride of sodium and aluminum mined in Greenland but occurring in Colorado) 50 to 64 percent, feldspar 22 to 18 percent, talc 11 to 9 percent, and calcium carbonate 11 to 9 percent. Cryolite has high fluxing power, as it dissolves many oxides such as those of aluminum and magnesium, and is therefore used in their welding.

Binders for Coatings

Sodium silicate. - The binders or agglutinators for coatings are tabulated later, but the common binder for coating mixtures is an aqueous solution of sodium silicate, Na_2SiO_3. Potassium silicate is also used, being cheaper (in Europe) than the sodium compound. Both serve as flux ingredients in the coating. Sodium silicate is white to gray-white as lump or powder and is soluble in water and alkalis but insoluble in alcohol and acids. It is marketed dry or wet as solutions of various concentrations ranging from viscous semiliquids to thin, watery fluids. It has many uses, including the binding of minerals on electrodes, according to The Condensed Chemical Dictionary.

In British Patent 425,443 (1935), a plasticizing agglutinant (any viscous substance that causes objects to adhere to one another) is added to the coating mixture, and the coated rod is heated to dehydrate it. In this case the agglutinant consists of 3 percent water-soluble glue, 3-1/2 percent inorganic ester of glycol, such as boron ester and 16 percent water. This agent acts as a reducing substance. (Boron esters are mentioned in other patents.)

United States Patent 2,158,984 (1939), issued to A. R. Lytle and T. H. Vaugh and assigned to the Oxweld Acetylene Co., calls for a metal core, such as one of bronze, provided with a coating of borax and boric acid, together with a thermoplastic resin, which emits no disagreeable fumes and deposits no char that would interfere with the welding operation.

Dextrin, a gum as powder or granules made from various organic materials, starches for example, is also used as a binder. It is soluble in water but insoluble in alcohol and ether.

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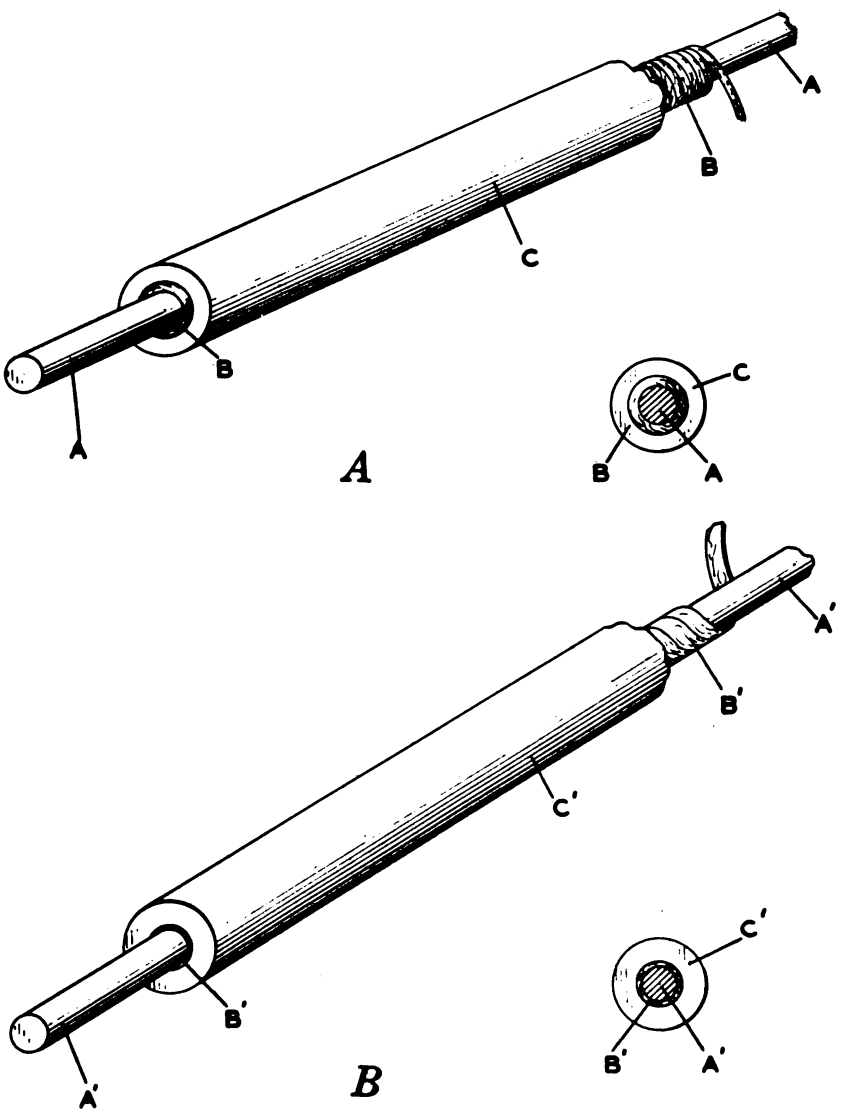

Figure 5.- Wrapping and coating as described. A, With fibrous asbestos; B, with asbestos paper.

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Wrappings on Electrodes

Although many coatings are applied wet to electrodes and then dried, several methods or devices are employed to hold or anchor them thereto and also to perform certain functions in the welding.

An early United States patent (No. 1,301,331, 1919, issued to R. S. Smith) employs paper that has been impregnated with sodium silicate before or after being wrapped around the wire or rod, then the electrode is baked to expel part of the moisture and harden the surface of the paper covering. With such an electrode, the insulating coating disintegrates slowly in the heat of the electric arc, the wire fuses or volatilizes more quickly, and the metal flows from the crater or crucible formed by the coating to the work to be welded and is deposited thereon and incorporated therewith. The paper covering, having a carbon content, does not form a slag, protects drops of metal from the welding rod from contact with air, and the joint formed is free from porosity and is homogeneous.

United States Patent 1,937,574 (1933), issued to R. S. Johnson and assigned to A. Roeblings Sons Co., calls for several strips of asbestos paper laid longitudinally with the axis of the rod and upon which is placed a plastic coating of 200-mesh 48-percent silica, 10 percent iron oxides, 6 percent manganese dioxide, 23 percent calcium oxide, and 13 percent titanium dioxide, with sodium silicate binder.

United States Patent 1,944,753 (1934), issued to D. L. Mathias and assigned to the Westinghouse Electric and Manufacturing Co., consists of a rod provided with longitudinal or helical grooves or with a combination of notches and grooves in which wires are laid for the purpose of anchoring the flux coating.

United States Patent 1,983,552 (1934), issued to M. L. Luckenbaugh and T. D. Radcliffe and assigned to the Standard Oil Co. of California, covers wrapping of the rod with fibrous cellulosic (cotton yarn) material and giving it an alkaline soak, a drying, a silicate soak, a drying, a silicate dip, a setting, a drying, and an aging.

United States Patent 1,985,974 (1935), issued to Frank Cardozo and assigned to the Standard Oil Co. of California, provides for a sleeve of rayon on the rod and a coating of sodium silicate formed thereon.

United States Patent 1,993,789 (1935), issued to R. S. Johnston and assigned to John A. Roebling's Sons Co., has a rod with a wrapping of fibrous asbestos or asbestos paper to hold a coating of silica, iron oxide, and a manganese mineral or titanium oxide. Figure 5, A and B, shows elevations and cross sections of the respective electrodes.

United States Patent 2,063,182 (1936), issued to W. B. Miller and assigned to the Union Carbide & Carbon Corporation, relates to a welding rod having a fabric on the bare metal and a coating of arc-stabilizing

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material. The wrapper may consist of a strip or tape of woven cotton or felted cotton fabric or a linen fabric or vegetable matter wound spirally about the rod or applied longitudinally. The wrap first may be impregnated with sodium silicate or only the ends of the fabric may be so impregnated. The flux coating is pulped and applied outside the fabric.

Powdered Metals and Minerals

As in other branches of metallurgy and manufacture, powdered minerals and metals are being used increasingly in welding. For instance, aluminum powder, iron powder, magnesium powder, solder powder, tin powder, and zinc powder are being employed. (Of course, the minerals composing the coatings and fluxes are powdered or ground before being mixed and applied to the rod

In United States Patent 2,009,240 (1935), issued to A. T. Roberts and J. H. Paterson and assigned to the American Murex Corporation, an iron or steel rod or wire carries a protective coating containing powdered metal of substantially similar composition as the core metal in an amount sufficient to supply a substantial part of the metal of the weld, and which also may contain manganese powder and china clay or colloidal silica. The same firm, in Canadian Patent 354,513 (1935), employs powdered iron and ferromanganese in the proportion of 6 percent manganese to the powdered iron, an not less than 10 percent of the welding rod is coating.

A correspondent of The Metal Industry (London), February 9, 1940, believes that the welding industry is another field in which powder metallurgy is destined to play an important part. An obvious direction is in th use of powdered metals as welding-rod coatings to supply constitutents that today have to be added in a diluted form with consequent loss of efficiency

Porous metals are being used more, as, for example, absorbing oil for "oilless" bearings. United States Patent 2,180,813 (November 21, 1940, issued to John T. Marvin and assigned to General Motors Corporation) covers molding finely divided metal powder into the desired shape, sintering the molded powder to cause it to fuse together and form a strong, highly porous electrode of homogenous character, and then impregnating the porous metal electrode with suitable nonmetallic fluxing ingredients, which solidify and are thereby held within the pores of the completed electrode.

Flux-Impregnated Tape

Patents have been issued for tapes or cords impregnated with a flux. United States Patent 1,884,712 (1932), Lincoln Electric Co., covered a cord of combustible material, such as twisted paper, for carrying the fluxing and alloying ingredients, such as alkali metal compounds, which may be fed into the arc area independently of electrode or work.

British Patent 430,722 (1935) issued to the British Thomson-Houston Co. includes a tape of cellulosic material (cotton, for example) impregnated wit powdered feldspar, titanium dioxide, ferromanganese, and sodium silicate

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and folded longitudinally about an electrode core with edges abutting one another and paralleling the axis of the core. A substantial layer of flux may be provided between the core and tape.

United States Patent 2,164,104 (1939), issued to H. C. Bereit and assigned to Una Welding, Inc., calls for the conjoint use of a welding wire and a flux-carrying tape in arc welding. The tape is fed simultaneously with the wire to the arc.

British Patent 483,566 (1938) issued to T. C. R. Shepherd and Metropolitan-Vickers Electrical Co., includes a white asbestos yarn spun on the electrode and the flux applied thereon; or powdered asbestos is added to the flux, which is applied to the electrode by extrusion.

Many of these inventions are recent and possibly have merit, although the authors have been unable to learn any special advantages for separate use of flux-impregnated tape in arc welding. Doubtless it is convenient in gas welding compared with dipping the hot welding rod periodically into powdered flux. Use of separately fed tape carrying the welding fluxes and minerals is probably not subject to the same patent control as are coated welding rods.

Organic Coatings

Certain types of coatings contain a high proportion of organic material such as alpha cellulose (cotton), and a carbohydrate material (wood flour). A number of patents have been issued for the use of the foregoing and for cellulose or like material in a fibrous or fluffy state (British Patent 443,925, 1936); for hydrocellulose or oxycellulose (British Patent 445,210, 1936); for flour and dextrin (United States Patent 2,152,286, 1939, to Pieter Schoenmaker); for cotton or paper (United States Patent 2,148,228, 1939, to R. R. Applegate); and for coke flour or lamp black or bone black for welding thin metal (United States Patent 2,043,927, 1936, to E. W. Kronbach, assigned to Una Welding, Inc.). Binders are used with these materials. All these fibrous materials can function as reinforcers to aid the binder, making the cracking of coatings less likely and providing a reducing atmosphere around the welding rod and weld metal.

Organic silicates, known as silicon esters, are proposed for coatings with other minerals. Ethyl orthosilicate, a colorless liquid with a density of 0.933, is an example. Talc or clay may be added. On standing in air, the moisture acts on silicon esters to liberate volatile alcohols and leave silica gel of good binding power. Any unhydrolyzed silicon ester can add volatile silicon to the weld atmosphere for protection against oxidation or even reduction of desired alloying elements.

"Borcote" is an organic filler made by the Foote Mineral Co. which reports that it is more alkaline (pH 8.09) than alpha cellulose (6.29) or wood flour (4.75). It is also nonhygroscopic and swells less in water than does alpha cellulose. It is less fibrous and extrudes better, producing

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a better-looking coating. There is no unpleasant odor when the rods are used, and the arc characteristics are better than those of alpha cellulose. Any boron compounds present add to the fluxing power of the coating, and any unoxidized boron could function like silicon esters as a reducing agent.

Features of Electrodes

Several features of coated rods may be listed:

Diameter ranges from 1/16 to 3/8 inch.
Length ranges from 9 to 18 inches.
Grip is at end or at center of rod bared 1 inch.
Composition of rod should approximate as nearly as possible that of the metal being welded.

Color of coating varies according to maker and to use. A Lincoln stable-arc electrode for general-purpose welding is a washed rod readily identified by the blue color. The McKay all-position electrodes for certain jobs are white, buff, cream, light red, black with blue tip, gray and red, and dark red. The Murex electrodes have brown coatings with brown, white, blue, gray, red, tan, orange, green, or violet tip; gray or tan with plain tip; cream with white tip; and white with black, blue, red, or violet tip for different purposes. The Roebling electrodes may be whitish, through gray, to black, the color depending primarily on the type of iron oxide in combination with manganese dioxide.

Cleanliness of rod before coating is essential.

Dip-coating of rods has been largely supplanted by extrusion methods.

There is no rule governing the thickness of a coating, yet there is an economic limit to it.

Nondeliquescent materials are needed in coatings - lithium carbonate, for instance, instead of lithium chloride.

Packing consists of 2- to 50-pound plain or corrugated cartons, tins, and bundles in burlap.

Proprietary Coatings

Following are a few examples of proprietary coatings as excerpted from patents issued:

Babcock & Wilcox coatings. - In Canadian Patent 356,161 (1936), for steel welding, a steel rod is coated with a mixture composed of 50 parts silicon carbide, 15 parts calcium carbonate (lime), and 10 parts calcium fluoride (fluorspar).

In British Patent 425,443 (1935), a coating consists of flint, manganese dioxide, magnetite, asbestos, and ferromanganese. A plasticizing agglutinant is added, and the coated rod is heated to dehydrate it.

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British Thomson-Houston coatings. - Several British patents were issued The British Thomson-Houston Co. during 1933 and 1935 for flux coatings on electrodes for welding steel. Feldspar, titanium dioxide, iron oxide, ferromanganese, silicon carbide, asbestos, and talc, with sodium silicate, are prominent ingredients. Analyses of steels for rods are given.

Champion electrodes. - Typical S. A. E. 1010 steel is used in the manufacture of steel welding electrodes of The Champion Rivet Co. according to the president, Pierre Champion. This analyzes 0.10 to 0.15 percent carbon, 0.40 to 0.60 percent manganese, 0.045 percent phosphorus, and 0.045 percent (maximum) sulfur. The elements used in the coatings are similar to the slag-forming materials used in the manufacture of steel, such as limestone, ferromanganese, silica, and various iron oxides. To these are added enough sodium silicate to render the mass plastic so that it can be extruded on the bare rods; also to serve as a binder, so that the coating will adhere to the electrodes.

General Electric coatings. - Recent coating patents of the General Electric Co. for steel welding include the use of feldspar, talc, siliceous clay, bentonite, ilmenite, kaolin, ferromanganese, or ferrotitanium with a binder. In one patent (United States 2,141,316, 1938, to A. M. Roberts), 25 to 60 percent siliceous clay is mixed with 75 to 40 percent manganese dioxide. Of these, we know feldspar and talc are fluxes and also provide slag-building ingredients; the clays provide slag-building ingredients, plasticity, and temporary binding power; the ilmenite provides titanium for arc stabilization, as almost universally used, and probably the grain refinement characteristic of small amounts of titanium metal entering the steel; the ferromanganese and ferrotitanium provide oxides for slag building and the brittleness of slag characteristic of manganese oxide, but function to protect the rod and weld metal from oxidation and nitriding. Other less obvious functions are probably also provided in some of these ingredients. General Electric markets its welding rods through Arcrods Corporation.

Haynes Stellite coatings. - The welding rods of Haynes Stellite for welding stellite or attaching tungsten carbide to steel drilling bits may be coated with many minerals. British Patent 467,034 (1937) calls for a core of iron or carbon steel, or it may contain up to about one-fourth of the alloying elements. The coating may also contain tungsten, molybdenum, vanadium, nickel, and cobalt to give 10 to 15 percent of the total metal in the deposit. The coating may consist of 7.5, 0, 0 parts calcium carbonate; 18, 19, 19 parts Albany slip clay; 3, 0, 0 parts rutile; 1.5, 0, 0, manganese ore; 45.9, 59.6, 48 parts high-carbon ferrochromium; 11.5, 9.9 6 parts silicomanganese; 7.6, 6.6, 22 parts low-carbon ferromanganese; and 5, 4.9, 5 parts cannel coal, with sodium silicate as a binder.

Metropolitan-Vickers electrical coatings. - Metropolitan-Vickers and T. C. R. Shepherd (and others) have a number of British patents for flux coatings for steel welding. One example (466,902, 1937) is 13 to 19 percent manganese dioxide, 11 to 20 percent feldspar, 27 to 39 percent ilmenite, 16 to 24 percent ferromanganese, 8 to 10 percent ferrotitanium and/or 10 to

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15 percent ferrochromium, and up to 6 percent kaolin. The mixture is made into a paste with sodium silicate or other binder.

Another example is Patent 483,566 (1938). The coating comprises one or more mineral silicates (feldspar or plastic clay), ilmenite, and titanium dioxide in the form of rutile and forming 40 to 60 percent of the whole mixture. The flux may also contain calcium carbonate, ferromanganese, and/or starch. Sodium silicate is the binder.

A third example is Patent 494,181 (1938), in which the flus is 35 to 45 percent ferric oxide, 20 to 30 percent silica, 10 to 20 percent ferromanganese, and 5 percent clay, with 15 percent starch made into a paste with sodium silicate or gum arabic and applied to an electrode by extrusion. The exact reasons for all these variations are not revealed but may be judged by a study of the table of functions of welding ingredients given in this paper.

Murex coatings. - Murex electrodes of Metal & Thermit Corporation for steel welding are of two general types - (1) those whose coatings are all mineral in content and are anchored to the core wires by spiral windings of asbestos yarn, and (2) those without such windings, whose coatings, which may contain other than mineral ingredients, are extruded on the core wires under high pressure. With either type, it is said, full protection from the atmosphere is provided during welding both to the arc and to the molten weld metal. Murex coatings are essentially mineral oxides, one of the most important being rutile. The oxides vary with the type of coating, and all of the coatings' compositions are especially made for each electrode. Cellulosic materials are sometimes used.

Roebling coatings. - For its coated electrodes, the John A. Roebling's Sons Co., Trenton, N. J., uses various proportions of the following materials according to C. C. Cooley, general sales engineer: Silica, calcium carbonate asbestos, iron oxides, titanium dioxide, manganese dioxide, manganese carbonate, aluminum oxide, ferromanganese, ferrotitanium, ceramic clay, and sodium silicate. The electrodes may be whitish, through gray, to black. In the absence of precise information as to the reasons for so doing, it is interesting to speculate on why manganese enters those coatings as the oxide, the carbonate, and the ferroalloy. There is a reason for each, but nowhere is there a frank discussion of principles involved in the design of weldrod coatings.

Westinghouse coatings. - Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa., gives no inkling of coating composition in its booklet "Crucible Weld Flexarc Electrodes." The firm has an electrode for every requirement and tabulates their characteristics as to size, current range, particular use, resultant arc metal, and how packaged. The metallurgy, chemistry, and ceramics involved in the formulation of these coatings is the trade secret of the company.

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Fluxes

Purpose of Fluxes

Critchett[13] defines the functions of flux as follows:

> At welding temperatures all metals oxidize (that is, form chemical compounds with oxygen from the air) more or less rapidly, and the oxides so formed act as so much "dirt." If permitted to remain in the finished weld, the oxide would seriously reduce the strength of the weld and might even make it quite useless.
>
> With most of the common metals, except steel, it is necessary to use a suitable flux to remove the oxides. This flux is a mixture of various chemicals which, at welding temperatures, will unite with the oxides to form an easily fusible slag.
>
> As the oxides of the different metals vary widely in physical and chemical properties, no one flux is suitable for all metals. There are, for example, separate fluxes for fusion welding of cast iron; for bronze-welding and fusion-welding of brass and bronze; for welding chromium alloys such as stainless steel; and for welding aluminum.

In a paper presented at the annual meeting of the American Welding Society, Chicago, December 1939, A. N. Kugler stated that the essential function of fluxes is to combine with or otherwise render harmless those products of the welding operation that will reduce the physical properties of the deposited metal or make the welding operation difficult or impossible.

Borax

As borax is used so much in welding, Kitchen's paper[14] on the mineral, presented at the meeting of the Division of Fertilizer Chemistry, American Chemical Society, Boston, September 11-12, 1939, should be procured or read in the reference below. Kitchen describes the occurrence (associated with clay and shale in arid country), refining, and uses of borax. Among the uses are brazing and welding. The metal surfaces to be joined must be clean and free of oxides. Borax, calcined borax, borax glass, and boric acid, alone or mixed, are among the most successful fluxes because they restrict the formation of metallic oxides and exert a solvent action on such oxides as are formed. Boric acid and its less expensive compounds are used in melting alloys of copper and nickel and in recovering them from scrap metals.

13/ Critchett, J. H., Fundamentals of Gas Welding: Welding Handbook, 1938, Am. Weld. Soc., New York, 1938, Chap. 8, pp. 127-128.

14/ Kitchen, E. M., Borax - Its Manufacture and Uses: Am. Fertilizer, vol. 91, September 30, 1939, pp. 7-9, 24, 26.

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A leading miner of borates and refiner of borax, boric acid, and such products informs us that approximately 500 tons a year of its boron products are sold for welding purposes and that possibly an equal tonnage is sold by other producers, making a total of 1,000 tons consumed annually in the United States for welding.

Borax occurs in aric regions as borax in crystalline salts and as brine in lakes; as colemanite in beds of limestone, dolomite, and clay; and as beds of clay and shale containing borax, colemanite, kernite, and ulexite within sediments and associated lavas (chiefly basalt), which lie upon older rocks that outcrop and younger granite and quartz monzonite.

Fluorspar

Fluorspar is used commonly as a flux. As in other fluxing operations, this mineral makes for fluidity in slags. Fluorspar is the cheapest of all the fluorine-bearing minerals that are easily available. Nearly all fluorides have high fluxing power. Cryolite is the only other natural fluoride available and used as a flux.

Fluorspar occurs as gravel or float material in clay, sandstone, limestone, and shale. Faults should be followed. Deposits are irregular. Associated minerals are barite, calcite, quartz, galena, and sphalerite.

Lime

In making iron and steel rod and wire, after acid pickling they are washed and then dipped in a lime emulsion. This dries on the metal and acts as a lubricant in drawing through the dies. Moreover, the lime and coating are useful for welding purposes. That lime is made from limestone by burning need hardly be stated here. Calcium can be an important ingredient in welding slag, whether it is introduced as free CaO (which is soon converted to carbonate on standing in air) or as powdered $CaCO_3$, or it may be introduced as the mineral wollastonite, $CaSiO_3$, to avoid formation of gas on heating. Wollastonite has not been used commonly in welding; but for steel it has about the right melting point, fluxing power, and brittleness as well as good heat-insulating properties, so that a weld will not cool too suddenly.

Lithium Minerals

Deliquescent minerals or salts can be used only in pastes, as lithium chloride, for example. Lithium carbonate can be used where deliquescence is to be avoided, or lithium aluminosilicates like spodumene, depending on the melting temperature of the metal being welded. The lithium compounds are noted for their extremely high fluxing power, lithia being more efficient from this basis than are the heavier alkali oxides.

Lithium as amblygonite, lepidolite, spodumene, and zinnwaldite occurs in pegmatites. Cassiterite and columbite accompany lithium minerals, which in welding are said to act as scavengers.

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Sodium Compounds

Sodium compounds are used in welding and The Condensed Chemical Dictionary (1919) lists a white flux powder consisting of sodium carbonate, sodium nitrate, and sodium nitrite. It is a strong oxidizer and a fire hazard and is shipped in tin cans. These salts are obtainable through chemical supply houses. Compounds of all the alkali metals are good fluxes, but the sodium compounds usually are the cheapest. The sodium tetraborate, borax, is unusual in having fluxing power in both its cation and its anion.

Special Fluxes

Several chemical compounds, produced from minerals, find use in coatings and fluxes as well as in soldering:

Sodium bifluoride, $NaHF_2$, is a white, crystalline, and poisonous powder soluble in water and selling at 12 cents a pound. It is a powerful flux of low melting point.

Pyrophosphoric acid, $H_4P_2O_7$, is a viscous, sirupy liquid that tends to solidify on long standing at ordinary temperature. Its melting point is 61° C. (141° F.). It is useful as a catalyst in certain processes and in the manufacture of organic phosphate esters. When diluted with water, pyrophosphoric acid is rapidly converted to orthophosphoric acid, which finds use in soft-soldering fluxes and leaves no residue to cause corrosion.

Phosphoric acid, H_3PO_4, a clear liquid or a transparent crystalline solid, depending on temperature and concentration, and its compounds are attracting some interest in the field of soldering fluxes because any acids remaining in the residue will react with the metals to form nonhydrolyzable metallic salts. Chlorides and sulfates hydrolyze readily and continue corrosion whenever moisture is present; but with phosphates, the acid, when once combined with the metal, remains fixed and its corrosive powers are exhausted, according to J. M. Gillet, Victor Chemical Works, Chicago. Phosphates are used in welding magnesium.

Alkyl acid phosphates, such as monoamyl orthophosphate, have good wetting powers, and the monoamyl phosphate in particular is interesting in soldering. No obnoxious fumes are given off when the work is done in a confined place; the spattering characteristic of some fluxes is eliminated and the corrosive residues are avoided.

Columbite, a blackish iron-manganese-columbium mineral that occurs with tantalite and is used in stainless steels, is also employed in welding these steels. Columbite has a gravity of about 5.3 and a hardness of 6. The streak is dark red to black. Several patents call for the inclusion of columbite in concentrates, as a metal and as an alloy. Silicon accompanies it. As in its use in stainless steel, some columbium is lost in welding.

French Patent 791,979 (1935) adds columbium and silicon to the soldering metal during welding; all or part of the former may be present in the

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flux as an oxide 25 to 75 percent, feldspar 5 to 35 percent, fluorspar 5 to 30 percent, borax 1 to 15 percent, silica 1 to 10 percent, and silicon or ferrosilicon up to 50 percent. British Patent 463,717 (1937) adds columbite as an oxidic compound in the flux and the silicon as such or as ferrosilicon or as columbium-silicon or as ferro-columbium-silicon. British Patent 459,367 (1937) uses a flux containing 2 to 40 percent columbium, either as such or as an alloy or in a coating on the rod.

In the application for two United States patents (2,121,770 and 2,142,045, 1938) for a welding flux and for a flux-coated welding rod, the use of columbium is specified. The welds of steels containing 2 to 16 percent chromium are brittle, those having 16 to 35 percent chromium lack satisfactory ductility, and those having 12 to 35 percent chromium, 6 to 35 percent nickel, and up to 0.3 percent carbon tend, when welded, to lose much of their resistance to corrosion. Therefore, it is proposed to add columbium to the metal to be welded and to the welding rod, preferably as finely comminuted ferrocolumbium in the welding flux, such flux to consist of about 5 to 30 parts columbium as ferrocolumbium, 30 parts feldspar, 10 parts calcium carbonate, and 5 parts chromite. The loss of columbium during welding may be reduced if silicon or aluminum is added to the flux. Gas-welding is as good as electric welding. One form of rod has a flux coat containing columbium and slag-forming materials, whereas another form has a flux coat containing columbium and an outer coat of slag-forming materials.

The second patent mentioned has electrodes similar to that described and is practically the same. Both patents say

> The results of these tests demonstrate the effectiveness of the flux of the invention to introduce columbium into the weld metal.

General Purpose Fluxes

United States Navy specification fluxes 51-F-2b, mentioned under their respective heads, are the principal types used in oxyacetylene welding and brazing for cast iron, brass, bronze, and aluminum, and the ingredients used in these formulas are practically the same as used in all oxy-acetylene welding and brazing fluxes.

Gaseous Flux

The new apparatus mentioned by Oliver[15/] in a survey of welding practice includes an improved gasfluxer of the Automatic Gasflux Co. (British Patent 507,632, June 16, 1939). This is made of aluminum and weighs only 6-1/4 pounds. It is connected with the acetylene or hydrogen line and supplies a flux vapor direct to the brazing flame. The flux, preferably an ester of an inorganic acid, such as boric acid, is said to be highly

15/ Oliver, Frank J., What's New in Welding Apparatus: Iron Age, vol. 144, November 1939, pp. 49-55.

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volatile, and a regulating valve gives a variable gasflux misture. Visual inspection of the liquid gasflux level is provided through a small window of reinforced glass. The fluxing agent is "other than an alkyl borate," whereas in British Patent 491,008, August 24, 1938, to the Linde Air Products Co., an alkylborate flux is mixed with the welding or brazing gas in the vapor state.

Slags

Forty to sixty percent slag-forming constituents are present in several prominent patented coatings, and Sprarogen and Claussen, cited later, believe that the composition of welding slags has not been studied comprehensively.

Considering that the slag in shielded-arc welding serves a number of purposes, such as (1) protection of the weld metal from oxidation and nitriding, (2) permitting slower cooling of the weld, (3) permitting the arc to play through the slag layer, (4) acting as a flux to keep metal surfaces clean, and so forth, it can be seen that the building up of the slag to perform these various duties is worthy of considerable thought. The slag must have the proper melting range, fluidity at the working temperature, dissolving power for oxides and nitrides that tend to form, heat insulation to permit a good cooling rate and yet allow desired depth of penetration of the welding heat, electrical conductivity to permit a quiet arc without too much volatile material being boiled away, and interfacial tension with solid and liquid metal to permit good fluxing, and, when cold, the slag must be brittle and easily removable. A good slag, properly protective of metal, permits use of a welding rod of about the same composition as the metal to be welded. Why the scientific aspects of slag formation, as permitted through correct blending of rod coatings, have not been discussed more in the literature is difficult to understand. One reason is that trade secrets can be kept successfully, as patent-law requirements do not demand that much of the "theory" underlying a coating formulation be disclosed. After a little thought is given to the items just listed, it is easy to see that a great field remains for research and publication along this line.

Action of Certain Fluxes

In their chapter on shielded-arc welding, Aschenbrenner and Deppeler[16] say that in the fluxing action of coatings,

> The molten slag in contact with the molten weld metal acts as a scavenger in removing oxides and other impurities from the weld. The fluidity of the metal is increased so that it flows more smoothly and uniformly. The result of the fluxing action is to produce better quality and to permit the deposition of layers of weld metal at high rates of speed.

These welding specialists also state that ingredients for producing slag are far too numerous and varied to be discussed thoroughly. For steel

16/ Aschenbrenner, F. J., and Deppeler, J. H., Shielded-arc Welding: Welding Handbook, 1938, American Welding Soc., 1938, Chap. 5, pp. 79-80.

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electrode coatings they are mainly metallic oxides, and they are often used in the form of natural complex silicates as asbestos and clay. A partial list includes oxides of titanium, zirconium, silicon, magnesium, calcium, aluminum, iron, manganese, sodium, and potassium. Common deoxidizers are the ferroalloys of manganese, silicon, and titanium. Stainless-steel electrodes often contain small amounts of fluorides to aid in dissolving any chromium oxide that may be formed.

Action of Slag in Welding

Slag is discussed, in part, by Henry and Claussen,17/ as follows:

> The nonmetallic material on the surface of the weld is the slag. If a bare iron rod is melted by arc or flame, the resultant bead will be covered with a thin layer of iron oxide. The flux in gas welding melts over the iron to form a coating of nonmetallic matter, which usually is spread on the rod. The slag is the molten (later solid) coating on the weld. Particularly with coated electrodes, the slag is not of the same composition as the coating or flux. Iron is absorbed, whereas other constituents may be lost during welding. Organic material, such as cellulose, in a coating forms a gas above 600° C., which dilutes the welding atmosphere; hence, it is low in oxygen and nitrogen, and high in gases containing hydrogen and carbon.
>
> Slag and surface tension. - Slag has an effect on the surface tension. * * * The surface tension of molten metal is always large - 100 times greater than water. Therefore, there is a large angle of contact between a weld scarf and a bare weld melt. If the molten metal is covered with slag having a low surface tension, the slag diminishes the contact angle and facilitates the penetration of the weld melt into narrow gaps, such as at the root of a butt or fillet weld. Surface tension and viscosity (its reciprocal is fluidity) are entirely different. * * * Whereas melts become rapidly less viscous as the temperature is raised, there is no corresponding change in surface tension.
>
> Alloying elements may change the behavior of a slag, which should not be too viscous nor undercut. Suppose the weld melt contains 1 percent aluminum: This has a high affinity for oxygen and forms Al_2O_3, melting at 2,050° C. (3,700° F.). The oxide joins the slag and makes it viscous and sluggish. As a result, the slag does not cover the melt adequately and tends to become entrapped in the solidifying weld. The dangerous effects of alumina may be counteracted by adding silica to the flux. Silica forms mixtures of low melting point with alumina.

17/ Henry, O. H., and Claussen, G. E., Welding Metallurgy: Am. Welding Soc., 1939, 47 pp.

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Specific gravity. - Specific gravity is particularly important in welding from a slag basis. If the slag has a higher specific gravity than the molten metal, which may happen in welding magnesium or aluminum with improper fluxes, the slag will collect mainly at the bottom of the weld melt. Surface tension under such circumstances usually forces a film of slag to cover the surface of the metal. The lower the specific gravity of a slag, the faster it will rise to the surface. It should be remembered that while gases have very low specific gravities, they may remain dissolved in metals.

FUNCTIONS OF INGREDIENTS IN COATINGS, FLUXES, AND SLAGS

The following functions of ingredients in coatings, slags, and fluxes were obtained from certain patents and writings, also from the writers' deductions in metallurgy and assaying.

1. Binders (in rod coatings and tapes):
   To hold powdered ingredients in desired shape and contiguity.
   Examples: Glue, dextrin, flour, clay, waterglass, colloidal silica, silicon esters, boron esters.

2. Thickeners for binders:
   To improve wet working characteristics upon forming coating.
   Examples: Bentonite in water, clay in water glass, permanganates or bichromates in lacquer.

3. Reinforcers (in rod coatings):
   To prevent cracking and peeling of bound coatings.
   Examples: Asbestos fiber, cotton fiber, mica flake.

4. Protection, solid coating:
   To cover rods and metal melting away from them for preventing attack by air.
   Examples: Easily oxidized rod metal, containing easily oxidized ingredients, show high loss due to oxidation when used bare and much smaller loss when the metal is coated. Coating should be slightly higher in melting point than metal coated.

5. Protection, from gas generated:
   An atmosphere of inert harmless gas around arc and melting metal prevents access of air.
   Examples: Organic powders introduced into coating, as wood flour, cellulose flour, charcoal.

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6. Protective slag over metal:
   Prevents access of air to hot metal. Slag formed from rod coatings, from metal oxides formed by attack on metal rod, and from fluxes added.
   Examples: Quartz powder, feldspar powder, clay, reducible metal oxides desired in weld metal.

7. Control of slag melting point:
   Each metal welded needs different slag.
   Examples: Calcium silicate melting point raised by magnesium silicate or alumina; calcium silicate melting point lowered by fluxes; mixtures of feldspars melt lower than any one alone.

8. Control slag viscosity:
   Must not be too fluid nor too sluggish.
   Examples: Alumina raises slag viscosity; fluxes lower it; silica forms mixtures of low melting point with alumina.

9. Control slag surface tension:
   Low surface tension helps spreading; high surface tension causes withdrawal into drops.
   Example: Fluxes lower surface tension and permit entrance of slag and molten metal into small openings.

10. Control slag electrical resistance:
    Example: If too nonconductive, add glasses, feldspars, fluxes.

11. Control slag specific gravity:
    Must be lighter than weld metal.
    Examples: Heavy metal silicates on aluminum must be diluted with light-weight, low-melting salts. Slag with higher specific gravity than molten metal will collect at bottom of weld, as with magnesium and aluminum.

12. Control slag properties for removal when cold:
    Examples: Brittle slags easily knocked off if manganese oxides added.

13. Control slag; metal interfacial tension:
    High interfacial tension promotes spreading and covering of metal surface.
    Examples: Manganese minerals and ferromanganese are good.

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14. To control heat insulation of slag cover:
Usually quick cooling of metal is not desired.
Examples: Slags of low viscosity and low surface tension spread too thin a coating. Deep penetration of weld for thick metal; shallow for thin.

15. To provide fluxes of metal oxide films and inclusions:
Examples: Solid inclusions of alumina when fluxed are liquefied and squeezed out by weight of metal. Film of oxide from metals welded must be dissolved by molten flux to permit blending of molten metals. Aluminum requires fluoride and halide fluxes. Iron works well with silicate fluxes. Borax almost a universal flux.

16. To control spattering of flux:
Examples: Borax spatters while melting; fused borax evolves no steam while melting. Alkyl acid phosphates diminish spattering of soldering flux and low melting fluxes for welding zinc, magnesium, and aluminum.

17. To provide volatile fluxes for penetration into recesses more efficiently.
Examples: Boron esters, boric oxide, ammonium chloride for cleansing.

18. To stabilize arc:
Accidental small movements of welder's hands must not extinguish the arc.
Examples: Rutile in steel welding; fluorides in aluminum welding.

19. To control arc resistance:
Must not be too conductive nor too resistant.
Examples: Rutile, volatile fluxes.

20. To provide weld metal in addition to that from rod:
Examples: Iron powder in rod coating.
Alloying elements in rod coating; saves a variety of analyses of rod metal.

21. To provide reducing agents for oxides in coating.
Examples: Charcoal, wood pulp, ferromanganese, ferrosilicon, silicon esters.

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Description of Functions of Individual Constituents of Welding Fluxes

1. Virdis Miller, assignor of United States Patent 1,978,318, October 23, 1934, to the General Electric Co., says that a welding flux of the following composition by weight is particularly suited (probably for steel, although not stated):

Mineral	Percent	Limit of variation, percent
Bentonite clay	1	0 to 5
Sodium hydroxide	4	1 to 10
Sodium carbonate	2	1 to 5
Titanium dioxide	18	10 to 40
Feldspar	53	25 to 74
Water	22	12 to 40

The base of this flux is feldspar, which, in the presence of titanium dioxide becomes viscous, causing the flux to remain where it collects over the molten metal. In the presence of titanium dioxide, it has no tendency to run down under the arc and stop the welding operation. I prefer to use a potassium feldspar, but other forms of feldspar may be used without departing from my invention. Sodium hydroxide forms with the titanium dioxide in the flux a titanite, which has a beneficial fluxing action on the arc. The sodium hydroxide also acts to lower the melting point of the vitreous material in the flux, causing it to form over the metal directly behind the arc. Any other alkali hydroxide having a melting point substantially the same as that of sodium hydroxide may be used. For example, potassium hydroxide is a suitable material. The chemical reaction between the titanium dioxide and the alkali hydroxide is rather sluggish, but during the reaction enough water is given off to fill the molten slag with steam. This causes it to be very porous and very light, and the presence of the flux on the molten metal does not form depressions in the weld when enough of this material is used to form a satisfactory coating. The sodium carbonate has a fluxing effect on the molten metal. The bentonite clay above referred to is a hydrated aluminum silicate which forms a viscous solution or suspension with water. It has a colloidal property and is sometimes referred to as a colloidal clay. This material holds the water in the flux long enough to prevent its being melted until the arc is quite near to it. This makes the flux melt at the proper time and prevents the arc from shifting out of the pool. By reason of its presence, the flux is used at the proper time and the resultant weld material is cleaned more effectively. * * *

The solid materials in the above flux are preferably in a finely divided state and form a paste when mixed with the water specified. The material should be thoroughly mixed to provide a flux of uniform texture.

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When welding in accordance with the method disclosed and claimed in my above-identified application, this fluxing material is applied to the work as a coating at least an eighth of an inch in thickness and of sufficient width to leave on each side of the weld a retaining wall of unfused flux for that portion of the flux which is fused by the action of the welding arc as the arcing terminal of an electrode is traversed through the central portion of this flux coating. * * *

Alloying materials may be added to the above-identified material without departing from my invention, but I prefer to apply alloying material to the weld in the form of a filler strip.

2. In describing the flux coating on an electrode used in metallic arc welding, J. H. Humberstone, in United States Patent 2,010,722, August 6, 1935, assigned to General Electric Co., says:

The essential ingredient of the above flux 39 percent by weight of feldspar, 21 percent of ilmenite, 9 percent ferromanganese, and 31 percent liquid sodium silicate is ilmenite, the presence of which in substantial percentages in the flux causes it to form a slag which is characterized by its ability to cover the weld metal. If feldspar alone were used as a flux, the slag resulting therefrom would be very viscous and would not flow readily over the weld and cover it. When ilmenite is added to feldspar, the slag becomes fluid and its ability to cover the weld metal is increased. The surface of the weld metal also becomes smooth and of good appearance. The ferromanganese employed is used as a deoxidizer. It also increased the fluidity of the weld metal. It is, of course, apparent that other deoxidizing materials may be employed in place of the ferromanganese, and also that the deoxidizer may be completely omitted from the flux.

The feldspar may also be omitted from this flux without impairing its usefulness for most welding operations.

MANUFACTURERS OF WELDING RODS AND FLUXES

Following is a list of manufacturers of coated electrodes and welding rods or fluxes, according to the American Welding Society and other informants:

Air Reduction Sales Co., 60 East 42d Street, New York City.
American Steel & Wire Co., Cleveland, Ohio.
Anti-Borax Compound Co., Fort Wayne, Ind.
Arcrods Corporation, New York City.
Champion Rivet Co., Cleveland, Ohio.
Handy & Harman, 82 Fulton Street, New York City.

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Harnischfeger Corporation, 4400 West National Avenue, Milwaukee, Wis.
Haynes Stellite Co., Kokomo, Ind.
Hollup Corporation, 3357 West 47th Place, Chicago, Ill.
International Nickel Co., Inc., 67 Wall Street, New York City.
Lincoln Electric Co., Cleveland, Ohio.
Maurath, Inc., 7300 Union Avenue, Cleveland, Ohio.
McKay Co., Pittsburgh and York, Pa.
Metal & Thermit Corporation, 120 Broadway, New York City.
Page Steel & Wire Division, American Chain & Cable Co., Monessen, Pa.
Roebling's Sons Co., John A., Trenton, N. J.
Una Welding, Inc., 1615 Collamer Avenue, Cleveland, Ohio.
Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
Wilson Welder & Metals Co., 60 East 42d Street, New York City.

MINERALS AND COMPOUNDS USED IN WELDING

According to the claims of the 120 United States patents granted since 1933, the following minerals and other compounds are used in various compositions in and on rods and as fluxes. The arrangement is merely alphabetical:

Metallic and Nonmetallic Elements in Rods or Electrodes

Aluminum and alloys
  Aluminum metal
  Aluminum-silicon alloy
Carbon
Chromium
Cobalt
Copper and alloys:
  Copper metal
  Copper-nickel alloy (monel)
  Copper-silicon alloy
  Brass
  Bronze
Iron:
  Cast iron
  Malleable iron
  Wrought iron
  Steels
Lead
Magnesium
Manganese
Molybdenum
Nickel and alloys:
  Nickel metal
  Nickel-copper alloy
Phosphorus
Silicon
Silver
Sulfur
Vanadium
Zirconium

In Coatings

Alkaline-earth silicates
Alkaline chlorides
Alkaline sulfates
Alumina
Aluminum powder
Aluminum silicates
Alundum
Asbestine
Asbestos
Asphaltum
Barium carbonate
Barium peroxide
Binders or agglutinators:
  Cellulose
  Dextrin
  Gelatine

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- Glue
- Gum arabic
- Paper pulp
- Potassium silicate
- Resin
- Shellac
- Sodium silicate and water glass
- Starch
- Varnish
- Wax
- Wood pulp or flour

Borax
Borosilicates
Boron esters
Calcium carbonate
Calcium silicate (wollastonite)
Cellulose acetate
Cerium sulfate
Charcoal
Chromite
Clays:
- Albany slip clay
- Bentonite
- China clay or kaolin

Coal:
- Anthracite
- Bituminous (20% volatile)
- Cannel (48% volatile)

Columbite
Corn cob
Diaspore
Fabrics for wrapped rods:
- Asbestos
- Burlap
- Cotton
- Rayon

Ferro-alloys:
- Ferrochromium
- Ferromanganese
- Ferrosilicon
- Ferrotitanium
- Ferrovanadium

Formaldehyde
Gilsonite
Glass, ground
Graphite
Hydrofluosilicic acid
Iron-containing silicates
Iron filings
Iron minerals:
- Hematite
- Magnetite
- Siderite

Iron powder
Lampblack
Lime (burned)
Lithium chloride
Magnesium-containing silicates
Magnesium-nickel
Magnesium-silicates
Manganese minerals:
- Pyrolusite
- Rhodochrosite
- Rhodonite

Mica
Mineral spirits (distillate between gasoline and kerosene)
Nickel-silicon
Nitrocellulose
Oils, natural:
- Cottonseed oil
- Pine oil

Oxycellulose
Petrolatum
Phosphorus pentoxide
Pitch
Potassium compounds:
- Potassium borate
- Potassium chloride
- Potassium nitrate
- Potassium oxide
- Potassium silicate

Pumice
Silica:
- Flint
- Quartz

Silico-manganese
Sodium compounds:
- Sodium acetate
- Sodium carbonate
- Sodium hydrate
- Sodium oxide
- Sodium resinate

Strontium
Talc
Tallow
Tantalum

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Thermit (iron oxide and powdered aluminum)
- Alumino-thermit
- Calco-thermit
- Magneso-thermit
- Mangano-thermit
- Silico-thermit
- Titano-thermit

Titanium minerals and alloys:
- Ferrotitanium
- Ilmenite
- Rutile
- Titanium metal
- Titanium dioxide

Tungsten:
- Borides
- Carbides
- Silicides

Vegetable matter
Water
Wollastonite

In Fluxes

Alkali metals:
- Carbonates
- Chlorates
- Chlorides
- Dichromates
- Fluorides
- Nitrates
- Perchlorates
- Permanganates
- Persulfates

Aluminum powder
Ammonium chloride
Ammonium fluoride
Barium chloride
Borates and borax products:
- Borax
- Borax glass (fused)
- Boric acid
- Boron ester
- Colemanite (calcium borate)

Cadmium compounds:
- Cadmium chloride
- Cadmium iodide

Cryolite, chiolite
Ethyl orthosilicate
Feldspar
Fluorides
Fluorspar
Graphite
Lithium fluoride
Petroleum coke
Phosphate salts and acids
Silicon carbide
Sodium compounds:
- Sodium acetate
- Sodium-ammonium phosphate
- Sodium borosilicate
- Sodium chloride
- Sodium fluoride
- Sodium silicate

Solder powder (40 tin: 60 lead)
Tin bromide
Tin chloride
Water
Zinc minerals and compounds:
- Zinc powder
- Zinc oxide
- Zinc-ammonium chloride
- Zinc bromide
- Zinc chloride

PRINCIPAL CONSTITUENTS OF SOME WELDING COATINGS AND FLUXES

As of August 1939, the Foote Mineral Co., Philadelphia, issued a list of 35 welding materials, which is available on request. Each mineral has a typical analysis, and we tabulate the principal constituents:

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Welding Product (Foote)

Name	Principal constituents	Percent
	Fluxes	
Fluorspar	Calcium fluoride	98.10
Magnesium oxide, calcined	Magnesium oxide	90.90
Marble (crystalline calcium carbonate)	Calcium carbonate	96.40
Wollastonite (calcium metasilicate)	Silica	49.80
	Calcium oxide	46.52
Strontium carbonate:	Strontium carbonate	92.56
Barium carbonate	Barium carbonate	1.47
Calcium carbonate	Calcium carbonate	3.46
Borax glass	Sodium tetraborate	100
Lithium fluoride	Lithium fluoride	98.7
Lithium chloride	Lithium chloride	98.1
Rare earth hydrate	Rare earth oxides	85
	Coatings	
Titanium compounds:		
Rutile	Titanium dioxide	94.10 to 96.70
	Iron	2.20 to 1.12
Titanalba	Titanium dioxide (pure)	98.8
"Ilmenite" (Indian)	Titanium dioxide	60.35
	Ferrous oxide	12.29
	Ferric oxide	24.59
	Alumina	1.24
Ilmenite	Titanium oxide	45.6
Manganese compounds:		
Manganese dioxide	Manganese dioxide	86.4
	Manganese oxide	2.7
	Ferric oxide	2.15
Manganox (manganese oxide)	Manganese oxide, brown	64.09
Rhodonite (manganese silicate)	Manganese	31.90
	Silica	30.20
Manganese carbonate	Manganese carbonate	68
	Calcium carbonate	13
	Iron carbonate	7
	Silica	13
Iron compounds:		
Ferrobest asbestos (iron silicate)	Ferric oxide	39.10
	Silica	50.90
Magnetite	Ferrous oxide-ferric oxide	94.07
Micaceous hematite	Ferric oxide	95.29

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Name	Principal constituents	Percent
Silicates:		
Magnesium silicate	Silica	51.60
	Magnesium oxide	30.10
	Ferric oxide	6.98
	Aluminum oxide	2.66
Amphibole (calcium magnesium silicate)	Calcium oxide	13.5
	Magnesium oxide	22.5
	Ferric oxide-aluminum oxide	5.0
	Silica	56.5
Aluminum oxide	Alumina	95.5
	Silica	1.5
	Titania	2.5
Clay	Alumina	47.09
	Silica	45.60
	Alkalies	1.19
Bentonite	(Sodium-calcium-magnesium-alumino-silicate)	-
Magbond (colloidal gelatinous binder and lubricant when water is added)	Silica	31.38
	Calcium oxide	24.26
	Magnesium oxide	11.29
	Sodium oxide	3.19
Beryl	Beryllium oxide	11.85
	Aluminum oxide	22.50
	Silica	62.0
	Alkalies	2.31
	Alkaline earths	1.70
Zircon, milled	Zirconium oxide	66.64
	Silica	31.00
	Titania	94

Alloys and metals

Ferromanganese:		
Standard grade	Manganese	80.30
	Carbon	6.47
Standard grade (nongassing)	Same	Same
Medium carbon grade	Manganese	83.57
	Carbon	1.35
Medium carbon grade (nongassing)	Same	Same
Ferromolybdenum	Molybdenum	58.67
	Silicon	1.57
Ferrotitanium	Titanium	22.54
Ferrochromium	Chromium	69.90
	Carbon	4.95
Tungsten metal powder	Tungsten	98.60
	Carbon	.53
Cobalt metal	Cobalt	97.0
	Nickel	1.2
Iron powder	Iron	96.6
Nickel powder	Nickel	98.88

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METALS THAT CAN BE WELDED AND THE COMMON MINERALS USED

Aluminum, copper and copper alloys, iron (cast, wrought, and malleable) and steel and steel alloys, lead, magnesium and magnesium alloys, nickel and monel metal, and silver are weldable. The metallurgical, chemical, physical, and thermal characteristics of the metals greatly influence their weldability.[18] Within their class, some of the metals weld better than others, and a factor in this is the use of proper fluxing material. Jennings[19] covers the welding of 29 metals and alloys, and excerpts are to be found herein.

Aluminum

Aluminum is a readily weldable metal, yet it has characteristics of its own that involve a technique somewhat different from that required by iron, steel, and other metals. All aluminum is coated with a thin film of oxide, and a proper flux is essential for either type of welding to remove the film during the welding operation. A flux should be used when aluminum castings are welded to cause the oxide particles to rise to the surface and result in a clean, sound weld. The amount of flux used per 100 feet of torch weld ranges from 2 pounds for 1/16-inch-gage sheet, using oxy-hydrogen, to 18 pounds for 5/8-inch gage, using oxy-acetylene, as stated in the Aluminum Co. booklet "The Welding of Aluminum," 1936. A welding rod of similar composition to that of the job is necessary. Much aluminum rod is now being coated, four firms doing this. The Aluminum Co. of America informs us that its compounded fluxes consist mainly of the chlorides and fluorides of sodium, potassium, and lithium. No. 22 flux is for torch welding, and No. 25 is a dip-coated electrode. The percentage composition of the fluxes cannot be divulged. The rod (weld metal) is generally a 5-percent silicon alloy, although weld metal of different composition may be used to conform to the properties of the alloy being joined.

According to the Northern Aluminum Co. "The Welding and Riveting of Aluminum," 1938, fluxes are most frequently mixtures of alkaline halides or sulfates, such as fluorides, chlorides, sulfates or bisulfates of sodium, potassium and lithium, and often contain cryolite, the double fluoride of aluminum and sodium. Several good fluxes are on the market. They can be used as a paste or dry, the welding rod being dipped into the powder. All traces of flux should be removed after a weld is complete, because fluxes are corrosive to aluminum. A wash with hot water, followed by hot 5-percent nitric acid or 10-percent sulfuric acid, and hot water again should be enough. If a little acidified 2-percent silver-nitrate solution placed on the joint gives a white precipitate, the cleansing has been insufficient.

Flux-coated electrodes are essential for the satisfactory metallic arc welding of aluminum and its alloys. Electrodes of almost pure aluminum

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18/ American Society for Metals, Welding of Metals, by a Committee of Specialists, Metals Handbook, 1939, pp. 221-259.

19/ Jennings, C. H., How to Weld 29 Metals: Westinghouse Electric & Mfg. Co., East Pittsburgh, 1937, 100 pp.

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can be used, but generally the most satisfactory results are obtained with an electrode containing about 5 percent silicon, although too much silicon lowers the safe temperature to which some of the strong alloys may be heated later - not above 930° F. Carbon arc welding is not as flexible as metallic arc welding for aluminum, according to Jennings.

A French patent (814,433, 1937) covers an electrode with its outer coating of higher melting point than that on the inner zone, and a British patent (485,741, 1938) is for coatings with melting points the reverse of the first patent.

Directions on the Oxweld Acetylene Co. container of cast-aluminum flux for welding aluminum castings state that the welding rod should be warmed with the blowpipe flame and then dipped into the flux and, after welding, all traces of flux should be removed completely by washing thoroughly with warm water.

United States Navy specification 51F2b for aluminum flux is 32 percent sodium chloride (common salt), 24 percent potassium chloride, 24 percent lithium chloride, and 20 percent sodium fluoride. These ingredients are almost the same as those used in all oxy-acetylene welding and brazing fluxes

Bliss, cited, says that scores of formulas have been suggested or patented. The halides of the alkalis have proved to be the best fluxes for aluminum oxide. Lithium fluoride and lithium chloride are the "aristocrats" of aluminum welding fluxes, and all the better fluxes on the market contain these salts.

The fluxing compounds mentioned can be obtained from chemical supply firms.

The Chemical Formulary (vol. III, 1936) gives the following flux for welding aluminum: Potassium chloride, 79 ounces; sodium chloride, 16 ounces; potassium bisulfate, 5 ounces. This flux is best used with welding aluminum containing 4 percent silicon.

Lithium chloride and lithium carbonate are used as fluxes in welding aluminum and other metals to dissolve the oxide coating and to prevent oxidation of the molten metal.

E. R. Thews, the well-known metallurgist, writing on repair welding of light metal castings in Metal Industry (New York) for February 1940, said that the solvent fluxes for aluminum oxide should melt just below the fusion temperature of the alloys welded. He also discussed the effective constituents of fluxes, as already mentioned here, and the need for perfect mixing of the high-and low-melting minerals in fluxes.

According to United States Patent 2,112,578 (1938) granted to Hans Rohrig, the welding seams formed by the arc-welding of light metals, particularly aluminum, have been porous because of gas absorption and irregular from other causes. To overcome this, it is proposed to have a coating in

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two layers or sheaths. The following has proved to be satisfactory for pure aluminum: Inner zone, 22-1/2 to 40 parts sodium chloride, 37-1/2 to 50 parts potassium chloride, 10 parts lithium chloride, and 9-1/2 to 18 parts chiolite (a form of cryolite); outer zone, 15 to 45 parts sodium chloride, 30 to 50 parts potassium chloride, 5 to 15 parts chiolite, and 10 to 20 parts cryolite. If necessary, more than two zones may be formed.

Copper and Copper Alloys

Jennings, previously cited, states that the carbon-arc process employing a phosphorus-bronze filler rod produces the most successful results for welding copper. No coating on the rod or flux is required, but high welding speeds are necessary to prevent formation of cuprous oxide as well as other conditions. Shielded-arc phosphorus-bronze filler rods have been developed to produce satisfactory welds on copper. One containing 10 percent tin and 0.3 percent phosphorus is very suitable.

In welding Everdur, a copper-silicon (3%)-manganese (1%) alloy, the metallic-arc and carbon-arc processes may be used, preferably the latter. Everdur filler rods, with a little flux composed of 90 percent fused borax and 10 percent sodium fluoride, should be used. Everdur may be welded to steel.

Herculoy, a copper-silicon-tin alloy, may be welded similarly to Everdur.

For welding bronze, the Southern Oxygen Co. recommends that all parts be well cleaned with emery. The bronze rod should be heated and dipped into the dry flux and applied to the joint. When tubes or light parts are brazed, a thin paste should be made and applied. A number of good fluxes for bronzes are composed of fused borax and boric acid.

Bardtke[20] states that copper is welded as easily as steel, but precautions must be taken because it absorbs oxygen during conductivity, which is six times that of steel. A welding flux is not absolutely necessary, but it is advisable to use it on heavy sections. Suitable fluxes consist chiefly of borax.

United States Navy specification for a flux for welding brass, bronze, and copper calls for 40 percent sodium nitrate and 60 percent boric acid. These ingredients are virtually the same as those used in all oxy-acetylene welding and brazing fluxes.

Hook[21] states that in much welding of copper alloys a flux is usually desirable and generally necessary. He also says:

20/ Bardtke, Paul, Technique of Modern Welding: Trans. from 2d German edition by Harold Kenney, Blackie & Son, Ltd., London, 1933, pp. 148-152.

21/ Hook, I. T., Copper and Copper alloys: Welding Handbook, 1938, American Welding Society, New York, 1938, chap. 30, pp. 569-570, 573.

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(a) Brazing flux. The usual commercial flux for silver soldering, brazing, bronze welding, and so forth, is frequently a mixture of anhydrous sodium tetraborate, $Na_2B_4O_7$ (calcined borax, fused borax), and boric acid, H_3BO_3. It may be used dry or suspended in water-free alcohol and painted on the work. If mixed in a small quantity and used immediately, it may be mixed with water. This makes an excellent flux for alloys carrying copper, zinc, tin, manganese, cadmium, lead, and iron.

It is moderately successful when silicon is present. It will not dissolve nickel, aluminum, chromium, or beryllium oxides, but may be used as a covering to prevent their formation, in part, at least.

Frequently, sodium chloride (common salt) is added to the borax-base fluxes for the welding of copper. It acts as a covering and cleansing agent. Occasionally, the flux is mixed with alkaline bifluorides to lower its melting point and make it more active.

(b) Flux for silicon on aluminum alloys. These fluxes are usually similar to the brazing fluxes, except that an addition of 10 to 20 percent of sodium fluoride; a sodium-aluminum fluoride (cryolite), is made.

No flux for satisfactorily dissolving beryllium or chromium oxide is known. However, by keeping the metals covered with one of the above fluxes, the refractory oxides of aluminum, nickel, chromium, and beryllium can be kept from forming to a certain extent and good brazes and welds can usually be made.

Except phosphor-copper brazing alloy, in the oxy-acetylene welding of electrolytic or ordinary copper a liberal application of a good brazing flux is desirable. It helps in the flow of metal and aids in keeping the metal surface free of scale. In carbon-arc welding, a flux is not essential, but a thin wash of a finely ground brazing flux suspended in alcohol on base metal and welding rod helps keep the metal clean and improves the flow of the weld metal.

Jennings says, with regard to bronze and brass, that both may be welded by the metallic and carbon-arc processes, but the composition and physical properties of the former vary over a wide range, and brasses contain zinc, which volatilizes during welding. Therefore, the procedure varies with these alloys.

Because of their difference in composition, red brass (85 percent copper) should not be brazed to yellow brass (70 percent copper).

Beryllium copper (2-1/2 to 4 percent beryllium) is best welded in a flat position by the carbon-arc process with subsequent heat treatment of the welded area. A little flux may be added.

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British Patent 472,371 (1937) provides for an electrode with a non-conducting flux coating of high melting point or of such wall thickness that the coating is fused off later than the core, so that a tubelike end is formed, excludes air, and renders the arc stable.

Iron and Steel

General

In the past, and on occasion at present, considerable welding of wrought iron and steel has been and is being done at the blacksmith's forge. The pieces to be welded first are enlarged or "upset" at the ends and then "scarfed" or beveled. Both ends are next brought to welding heat and, while in the fire, clean sand or borax is sprinkled on them. Then the beveled faces are laid on one another on an anvil and welded quickly by hammer blows. The oxide and dirt are forced out and a solid rod or bar results. Skill is necessary. One man can handle small welds, but two are needed for large pieces. The enlargment caused by the weld can be swaged down to normal size on reheating.

Under the auspices of the Literature Division of the Engineering Foundation Welding Research Committee, Spraragen and Claussen[22/] review coatings and fluxes in the welding of steel, and excerpts from their paper appear here and in other parts of this report.

They find that no single type of composition of coatings or flux is best under all circumstances. Coatings are difficult to classify. At present, the division into organic and inorganic seems most useful, although some authorities prefer to subdivide the inorganic into flux-coated (mainly sodium and calcium compounds) and slag-coated (mainly silica and silicates) and to include a mixed organic-inorganic type. The review reveals many differences of opinion regarding coatings and fluxes, and space is not available to reprint the findings on the numerous minerals tested and tried.

Although there may be other functions of electrode coatings, 19 are listed. These include the effect on the welding atmosphere; stabilizing the arc; performing metallurgical refining operations such as deoxidation; producing a smooth weld; dissolving scale or rust; providing a slag of low melting point, low density, and low viscosity; making good the losses of metallic elements in the electrode by burning; adding alloying elements to the weld metal; permitting a longer arc to be held, so that globules do not short-circuit the gap; retarding the rate of cooling and solidification of weld metal; permitting use of different types of current; reducing spatter or fume; and providing a slag that is easily separated from the deposit, a slag that is immiscible in weld metal, and a slag to cover the weld puddle completely.

22/ Spraragen, W., and Claussen, G. E., Coatings and Fluxes in the Welding of Steel - A Review of the Literature to January 1, 1938: Welding Jour., vol. 18, May 1939, pp. 153-165, including 1 page of 144 references.

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Spraragen and Claussen state that as there is an almost complete absence of systematic research on steel-welding fluxes and, as there is a great assortment of proprietary compositions, little need be said of fluxes for gas and other methods of welding.

The slag in welding is a nonmetallic substance that covers the surface of the solidified weld. If the weld is made in a neutral atmosphere with a bare rod, no slag is present. A covering of iron oxide gathers on the surface of bare electrode welds deposited in air. The physical behavior of the slag during welding is not fully understood.

Inclusions of gas or nonmetallic material such as silicates and sulfides have been blamed on occasion for the erratic behavior or spatter of an electrode. Inclusions in base metal, it may be supposed, exert the same effects as inclusions in the filler rod.

Viscosity of the slag and metal and the effect of surface tension are more or less important factors in welding.

Minerals Used and Their Effects

Common coating constituents used for slag-forming are silica, manganese dioxide, iron oxide, amphibole (a complex silicate of magnesium, calcium, and iron), rutile of 95 percent titanium oxide content, and feldspar (chiefly alkali aluminum silicate).

Asbestos. - Asbestos, the blue and white varieties, low in lime and respectively fibrous iron silicate and hydrated magnesium silicate, are essential constituents of coatings. Various effects are ascribed to these minerals. When made into a coating with sodium silicate, the blue variety decarbonizes the weld metal and lowers the manganese content, or it absorbs metallic oxides in the molten state, according to two investigators. The white variety, when magnesium ferrous silicate is added, yields an easy-flowing light slag. Sodium silicate is almost generally used as a binder.

United States Patent 1,937,574 (1933), issued to R. J. Johnston and assigned to John A. Roebling's Sons Co., includes a metal core coated with asbestos and with an overlying coating of at least 46 percent silica and also a flux containing oxides of calcium, titanium, and manganese.

Asbestos is found in serpentine as a rule, occurring as veinlets 1/2 inch to 6 inches wide. The principal mineral is chrysotile. The rock is cobbed and sorted and then milled. The price depends on the grade and length of the fiber, whether it be for spinning purposes or for making sheets and other forms. The United States produces some chrysotile (white variety), and Canada and Russia mine considerable tonnages; Transvaal produces crocidolite (blue variety) where it occurs in ironstone.

Graphite. - Graphite is used as a deoxidizer. Other minerals added to coatings for deoxidation are aluminum in several forms, silicon, manganese, titanium, vanadium, and boron as suboxide. Wood flour is also

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used for this purpose. Although there are exceptions, one investigator believed that alloying elements are always better added through the coating than through the rod.

Thermit. - Thermit welding has been termed a "casting process," with a scope only in the repair of heavy parts, such as of broken machinery, or the joining of steel rails. "Thermit" is a trade name (Metal & Thermit Corporation) for a mixture of 2 parts finely divided aluminum and 1 part iron oxide, with alloying elements as nickel and manganese. Up to a temperature of 2,800° F. it is inert. (It can be ignited with a strip of magnesium.) At that point, the aluminum unites with the oxygen of the iron oxide, and the iron is set free as a highly superheated liquid steel at a temperature of approximately 5,000° F., according to "Thermit Welding" of the Metal & Thermit Corporation. If the ends of the pieces to be united have been prepared and preheated as by a gasoline burner and the molten thermit run into them, the ends will be melted together into a homogeneous mass or a fusion weld. The excess metal is then trimmed off by hand or by machine, as is most suitable. Such welding may be seen along street railways in any city, but because of glare the operation should not be watched too long.

There are several modifications of thermit mix, such as alumino-thermit, calco-thermit, magneso-thermit, mangano-thermit, silico-thermit, and titano-thermit. United States Patent 1,953,382 (1934) to Franz Wortmann covers a rod of metal with 50 percent alumino-thermit, 15 percent silico-thermit, 15 percent mangano-thermit, 5 percent each of carbonates and hydrates, and the balance nondetrimental impurities.

Cast Iron and Steel

All cast irons save alloy cast irons are relatively weak and brittle, and special precautions must be taken to prevent cracks when they are welded. The use of coated electrodes has lessened the bother of poor fusion resulting from the ashy and sandy residue formed at the fusion zone, caused by the state of the carbon, according to Jennings.

United States Navy specification 51-F-25 calls for a flux containing 50 percent sodium nitrate, 27 percent sodium carbonate, and 23 percent sodium tetraborate for welding cast iron and steel. These ingredients are virtually the same as are used in all oxy-acetylene welding and brazing fluxes.

For welding cast iron and steel castings, the Oxweld Acetylene Co. suggests that the welding rod be warmed in the blowpipe flame and then dipped into its Ferro-Flux. This dissolves iron oxide and forms a fusible slag, which rises to the top of the weld. Sand and other impurities are also removed.

In welding cast iron, Glenn V. Ireland, United States Patent 2,171,306 (August 29, 1939), would avoid formation of white-iron layers in the weld because of their brittleness and extreme hardness in machining. He would

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use a low-carbon steel rod or low-carbon nickel steel, also a low-carbon coating and noncarbonaceous binder where possible, although a clear lacquer can function. The coating should include the compounds of boron, iron, and sodium with a deoxidizing agent like ferrosilicon, ferromanganese, phosphor-copper, magnesium, aluminum, ferrotitanium, or boron alloys. For applying the coating, the aqueous suspension of ground powders can be thickened with clay or bentonite. If a lacquer is used as a binder, it can be caused to jell or thicken by addition of potassium permanganate, chromic acid, or an alkaline chromate.

Tibbenham's[23] new book, for beginners and for experienced welders, is on the welding of cast iron by oxy-acetylene. Included are sections on fluxes and coated rods, but as we have had no opportunity to read this book.-only two favorable reviews.-his remarks on reagents used, are unavailable at this time.

Wrought Iron

Wrought iron is easily and strongly welded by gas or by arc. This is attributed to its self-fluxing slag or iron silicate content, which amounts to 1 to 3 percent in iron of the Aston or Byers process. The slag is distributed throughout the iron in the form of threads and fibers, which extend in the direction of rolling. Each material has its own fusion temperature - the iron at 2,730° F. and the slag component at 2,100° to 2,200° F. Sound welds result from the protection afforded the metal by the fluxing action of the slag, according to The Welding and Flame Cutting of Wrought Iron, A. M. Byers Co., Pittsburgh, 1939. Any high-quality, low-carbon rod, such as supplied by Air Reduction Sales Co. and Linde Air Products Co., should give satisfactory results with wrought iron in gas welding; and those of The Babcock & Wilcox Co., Champion Rivet Co., General Electric Co., Lincoln Electric Co., Metal & Thermit Corporation, Una Welding, Inc., and Wilson Welder & Metals Co. are suitable for electric welding. Rods that contain alloys of any kind are not recommended for use with wrought iron. Either bare or coated rods may be used.

Stainless and Rustless Steels

For stainless steels, different types of fluoride fluxes are reported to be the most satisfactory; fluorspar is generally used. Sodium or potassium bifluoride may be used with borax or borax and boric acid. The potassium salts are preferable to those of sodium. A flux of 1 part borax and 1 part boric acid made into a paste with a saturated solution of zinc chloride is suitable.

Jennings, previously cited, described the welding of stainless steels and other steels and irons at considerable length. He refers to the addition of titanium or columbium in 18:8 steel to prevent carbide precipitation.

23/ Tibbenham, L. J., The Welding of Cast Iron by the Oxy-Acetylene Process: Isaac Pitman & Sons, London and New York, 1939, 88 pp. (From Steel, Cleveland, Ohio.)

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They are also added to prevent intergranular corrosion. Kelley[24] (General Electric Co.) states that the brazing of stainless steel requires particular skill.

In welding rustless and stainless steels, the flux may be used dry (the welding rod being dipped into it) or wet as a paste. British Patent 431,584 (1935) covers a flux of 60:40 powdered borax glass and potassium fluoride.

Stainless-clad steel (20 percent stainless on mild steel) welding has presented a problem, but the Jessop Steel Co., Washington, Pa., has overcome this by scarfing the mild steel, bending over the cladding, welding the two claddings, turning over the welded plates, welding the underside of the cladding, and filling the hollow in the mild-steel backing.

A new method of welding zinc-coated iron by means of tin-coated electrodes and a carbon arc is reported.

Pick-Up and Recovery

Henry and Claussen, previously cited, discuss "pick-up" and "recovery" in welding iron and steel. They say, in part:

> Pick-up. - The third difference between the welding of plain-carbon and alloy steels is found in the behavior of the alloying elements in the weld melt. If we melt iron in air, the iron absorbs or picks up a little nitrogen and also reacts with oxygen to form an oxide slag. If we melt a high-carbon steel in air, the carbon in the steel reacts with the oxygen to form gaseous carbon monoxide, which bubbles out of the steel. There is a loss of carbon. Similarly, if we melt an alloy steel in air there may be absorption of gases, formation of slag, or loss in alloying elements.
>
> It is true that when we make a flanged weld without filler rod, the weld melt may pick up gases,***. The more usual sense of the term "pick-up" relates to the welding of an alloy steel with a filler rod of a dissimilar steel. For example, suppose we weld 3 percent nickel steel with a nickel-free plain-carbon steel rod: The operator melts the filler rod into the scarves, but also melts a little of the base metal to secure a perfect joint. The mixture of base metal with filler metal which forms the weld melt, therefore, contains some nickel, perhaps 1 percent the pick-up . .
>
> Pick-up is important in the welding of plain-carbon steel with 18-8 electrodes.***

24/ Kelley, F. C., Properties of Brazed 12-percent Chrome Steel: Iron Age, vol. 144, November 2, 1939, pp. 33-35.

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Because alloying elements may pass from base metal to weld melt, it might be supposed mistakenly that alloying elements also might pass from the weld to the base metal. The two situations are not identical. The weld melt picks up alloying elements from base metal because the latter is melted into the weld. The alloying element itself is not abstracted from the base metal; the alloying element and all other elements in the melted region are stirred into the agitated puddle. On the other hand, for alloying elements to pass from the weld melt to base metal they must enter and travel through the crystal of base metal. The passage of alloying elements through crystals of steel even at high temperatures is extremely slow, as the slow processes of nitriding and case-carburizing reveal.

Recovery. - "Recovery" is the amount of alloying elements in the weld deposited by the filler rod of any kind.

The deposit from a bare electrode containing 0.50 percent C generally will contain not over 0.05 percent C. The recovery is 10 percent. If the electrode is coated, the carbon recovery may rise to 50 or 100 percent, depending on the coating. Copper is recovered completely in depositing a copper-steel rod because copper has a high boiling point and less affinity for oxygen, nitrogen, and other gases that may be present in the welding atmosphere than iron. Silicon, on the contrary, often is oxidized completely from a bare electrode. Recovery of alloying elements, such as chromium and tungsten, is not a responsibility of the operator. The manufacturer of the rod may coat it, if the rod is for arc-welding, or may add some other ingredient or may employ a suitable flux which will reduce the element to the melt from the slag in gas-welding. Sometimes, electrodes have the alloying elements in the coating instead of in the rod itself. Low recovery of an alloying element may be due to the low boiling point of the element (volatility) or its tendency to join the slag (affinity for oxygen, nitrogen, or other gas), or to incorrect welding procedure (overheating of the melt).

British and European Problems

During May 1935 The Iron and Steel Institute, London, held a symposium on the welding of iron and steel and published two volumes[25] of the proceedings. Several well-known Americans and Europeans participated. The whole makes a valuable contribution to the extensive literature on welding;

25/ The Iron and Steel Institute (London), Symposium on the Welding of Iron and Steel: Vol. 1, Practice and Problems of Welding in the Engineering Industries, 1935, 676 pp.; vol. 2, Welding Practice and Technique, Including Welding Apparatus: The Metallurgy of Welding; Specification, Inspection, Testing and Safety Aspects of Welding, 1935, 974 pp.

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except for a few items here and there, the text does not fit in with this circular, but some excerpts have been made and incorporated. Spraragen and Claussen's review of the literature, cited here, refers to several of the papers.

Lead

Like silver, lead has the property of self-diffusion or flow at ordinary temperatures, and two surfaces brought together at moderate pressure will weld.

The uniting of pieces of lead is generally termed "burning," but it is a welding process. United States Patent 2,122,185 (1938), issued to A. A. Smith, Jr., and assigned to the American Smelting & Refining Co., claims the successful use of sodium acetate flux, added to the job either as a coating on the "burning rod" or as a powder. This material is suitable for joining lead or lead alloys as in storage batteries.

Magnesium and Magnesium Alloys

Considerable skill and cleaning and fitting of pieces are required for welding magnesium alloys, according to H. Menking, American Magnesium Corporation, Cleveland, Ohio, in Metals Handbook, 1939. The welding rod should approximate the composition of the work, and a special welding flux is needed. Preheating is advisable. After welding, the flux must be removed by hot water and a wire brush.

Oxy-acetylene is commonly used in welding, also magnesium chloride and some alkali as flux, sparingly and carefully removed soon after.

German Patent 671,534 (1939) would clean magnesium or its alloys with phosphoric acid, pyrophosphoric acid, or metalphosphoric acid or phosphates before soldering or welding with the halogen salt powder of patent 658,755 (1938), alkali or alkali earth chloride, and borate, oxalate, bisulfate or phosphate.

Two British patents (463,434 and 467,155, 1937) refer to fluxes for magnesium and alloys. The first patent covers the use of lithium chloride, potassium fluoride, and phosphoric acid; lithium bromide, potassium fluoride, and potassium orthophosphate; sodium orthophosphate, manganese dioxide, and a mixture of sodium chloride, potassium chloride, and lithium fluoride. (The second patent is a modification of the first.)

French Patent 796,600 (1936) was issued for a soldering agent for magnesium whose reaction products do not attack the metal. Potassium orthophosphate is said to be suitable, with 1 percent manganese dioxide.

In United States Patent 1,968,984 (1934) specifications, W. O. Binder (The Dow Chemical Co., only producer of magnesium metal in the United States) states in part:

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I am aware that many attempts have been made to develop welding fluxes suitable for use with magnesium and its alloys, and although a very few fluxes have been produced which can be so used, still none of such fluxes can be considered as wholly satisfactory. The melting point of magnesium 1,204°F. and its alloys is so low that difficulty is had in obtaining welding flux mixtures which will have a melting point lower than the melting point of the metal, are non-hygroscopic, do not react with the metal, and do not contain heavy metal compounds.***

***A specific composition suitable for practically all purposes in connection with the autogenous welding of magnesium and magnesium alloys is as follows: Barium chloride, 40 percent; potassium chloride, 30 percent; sodium chloride, 25 percent; lithium fluoride, 5 percent.

The first three listed are fused, and then the last is mixed; then they are pulverized suitably for coating the welding rod or for sprinkling over the welding area.

Because the common halide fluxes used in welding magnesium cause corrosion through inclusions of the flux in the weld, a further addition or treatment is necessary to prevent this. In United States Patent 2,171,041, August 29, 1939, J. M. Michel (assignor to the Magnesium Development Corporation) would use phosphoric acids and their acid salts to bring about volatilization of all halide during the welding. Some manganese dioxide assists. Monopotassium phosphate, boric acid, and even oxalic acid can be employed for the same purpose.

Nickel and Monel Metal

Nickel and monel metal are welded regularly by all the processes employed with steel.[26] The heavily flux-coated electrode of the shielded-arc type has improved the arc-welding characteristics of these metals.

Flocke and Schoener[27] say, in regard to fluxes when welding with gas:

A flux is always used for monel (except for gas-welding monel with the silicon-monel gas-welding rod for pickling service), but none should be used with pure nickel.*** Flux may be used either as a dry powder, into which the heated end of the rod is dipped, or preferably as a thin paste.

26/ The Lincoln Electric Co., Procedure Handbook of Arc Welding - Design and Practice: 5th ed., 1933, pp. 275, 277.

27/ Flocke, F. G., and Schoener, J. G., Nickel and High Nickel Alloys: Welding Handbook, 1938, Am. Welding Soc., New York, 1938, chap. 32, pp. 615-616.

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Borax improves fluidity of the molten metal, but when present in large proportions, the extra fluidity is accompanied by lack of ductility in the finished weld. Borax does not dissolve the metallic oxides sufficiently to produce the clean appearance sometimes necessary, and it is rather difficult to remove.

The flux used should not corrode the high nickel alloys and need not be removed on this account. However, it is usual procedure to remove it as a matter of cleanliness, and this is easily done by dissolving in warm water.

United States Patent 2,100,545 (1937), issued to H. W. Hiemke and assigned to A. O. Smith Corporation, covers nickel or nickel alloy rods heavily covered with a mixture of 12 parts titanium dioxide, 13 parts wood flour, 6 parts ferromanganese, and sodium silicate to protect the wood flour from premature decomposition and to enter the slag.

Graphite averaging 65 percent has been found "eminently satisfactory" for an alloy such as monel metal, according to United States Patent 2,139,522 (1938), issued to T. C. R. Shepherd and assigned to the General Electric Co. The carbon presents a shielding atmosphere during welding.

Silver

The following items are from Leach's[28/] notes on silver soldering:

Common borax and mixtures of borax ($Na_2B_4O_7$) and boric acid (H_3BO_3) have been used for many years as fluxes for silver soldering and brazing. Borax is fluid at 1,400° F., but begins to thicken at temperatures below this point. The addition of boric acid tends to make a more viscous flux, but it is not as active as borax in dissolving oxides of metals. Boric acid, when heated, does not bubble like common borax, but spreads over the surface of the joint, thus protecting it from oxidation. The bubbling of borax when heated results from the driving off of water of crystallization, but this can be avoided by using fused borax. Water must not be used to make a paste of fused borax, as it will rapidly cake, but alcohol is suitable.

The dry flux can be sprinkled along the joint, but if a torch is used for heating it is better to warm the joint so that the flux will adhere and not blow away. When filings of solder are used, the flux can be mixed with them before sprinkling along the joint.

28/ Leach, R. H., Silver Soldering: Welding Handbook, 1938, Am. Welding Soc., New York, 1938, chap. 18a, pp. 340-341.

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A thin paste is a satisfactory form because the flux can be brushed over the surface and an even coating applied. In brushing the flux, care should be taken to go back and forth over the surface to make sure that there are no bare spots.

When using borax as a flux, a hot saturated solution brushed along the joint will leave a heavy coating of flux.***

Prepared fluxes are made by reliable companies in the form of powder, paste, and solution, and can be purchased direct from the manufacturers or from supply houses or distributing agents. One should keep in mind that one of the advantages of silver solders is their low melting points (1,160° to 1,510° F.) and select a flux that is fluid and active at the melting point of the solder.

A low-temperature brazing flux is made by Handy & Harman. It is composed of approximately equal parts of potassium acid fluoride (KHF_2), potassium tetraborate ($K_2B_4O_7.5H_2O$), and boric acid (H_3BO_3). It melts at 760°, is completely fluid at 1,100°, and is stable up to 1,600° F. This flux will readily absorb metallic oxides at a comparatively low temperature and is particularly able to absorb chromium oxides — rather an advantage, particularly when work is being done with low-temperature brazing alloys that contain silver and have melting and flow points in a temperature range of 1,100° to 1,600° F.

(Although not concerned with fluxes, it is of interest that two silver sheets or strips in contact with each other will adhere at 200° to 400° C. at pressures up to 45,000 pounds per square inch. This so-called cold welding is accomplished by self-diffusion, also a property of lead. Butts and Van Duzee and Van Duzee and Thomas have covered this property of silver.29/)

Dissimilar Metals

Miller's review30/ of welding progress during 1939 refers to the welding of dissimilar metals. He says in part:

In percussion welding, a process claimed to permit in general the welding of any two pieces of metal without regard to their similarity as to thermal conductivity or material has been developed. Thus, a rod of copper may be welded to one of stainless steel; S.A.E. 1045 steel to stellite (cobalt, tungsten, chromium); zinc to aluminum; cast iron to copper, and others. Furthermore, heat-treated parts are said to be welded without affecting the heat treatment.

29/ Butts, Allison, and Van Duzee, G. R., Cold Welding of Silver: Trans. Electrochem. Soc., vol. 74, 1938, pp. 327-336; discussion, pp. 337-339. Van Duzee, G. R., and Thomas, J. M., preprint 77-6, April 29, 1940, pp. 78-82.

30/ Miller, R. E., Welding Serves Industrial Upswing: Iron Age, vol. 145, January 4, 1940, pp. 114-116, 118, 160-162.

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Monel or nickel can be welded to steel, also. In this process the two areas are brought into mechanical contact, simulating a hammer blow. This is the Vanco process of percussion welding, United States Patent 2,159,916, issued to Alfred Vang, May 23, 1939.

Fluxes for Certain Metals as Used by One Firm

Welding fluxes for bronze welding, cast-iron welding, aluminum welding, and stainless-steel welding are manufactured by The Linde Air Products Co., a unit of the Union Carbide & Carbon Corporation. These fluxes contain, in various combinations, the following materials, according to J. G. Romer, assistant manager, apparatus sales: Borax, boric acid, borax glass, soda ash, snow-flake crystals (?), iron oxide, salt (sodium chloride?), potassium chloride, lithium fluoride, and sodium borosilicate.

Early in 1940 this firm issued a chart of its recommended welding methods, flame adjustments, welding rods, and fluxes for welding a variety of commonly used metals and alloys.

WELDING INSTRUCTION

As may be judged from perusal of the foregoing pages, welding is metallurgy in miniature plus a special craftsmanship that must be acquired before the desired results can be obtained. Instruction in the craft is common, and many schools are mentioned in the following review of the subject. For training welders as craftsmen, this is as it should be; but certain technical schools for higher education should include instruction for the skilled metallurgist and should include a groundwork of principles in addition to teaching craftsmanship. This is done in several schools. E. G. West, in reviewing welding and weldability of certain nonferrous metals in The Metal Industry (London) for January 19, 1940, believes that "Every welding craftsman must be trained on a broad fundamental basis before details of the necessary technique can be fully appreciated."

Public Schools

In the District of Columbia, the Board of Education offered instruction in welding to apprentices for about 3-1/2 hours on 3 nights a week at the Abbot Vocational School recently closed. Electric and oxy-acetylene welding is taught. The class work includes instruction in fluxes and coatings. Spot welding and some brazing are done in McKinley High School in connection with forging and motor-vehicle work. The Southern Oxygen Co. supplies electrodes and fluxes.

In Pittsburgh, Pa., the Connelley Vocational High School, Board of Public Education, gives a 12-unit course in oxy-acetylene and electric arc welding. This includes setting up apparatus (1 unit) and manipulation of torch (2 units), about 70 units for welding iron and steel of various forms, 5 units each for aluminum and bronze, and 2 units each for copper and lead.

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Night courses in welding are now given by a unit of the public schools system in Salt Lake City.

Colleges

The Alabama Polytechnic Institute, Auburn, Ala., gives instruction and practice in welding irons and steels and nonferrous metals by the oxy-acetylene and electric processes, also consideration in the weldability of metals in the Department of Industrial Engineering and Shops. The laboratory fee is $3 each semester.

Carnegie Institute of Technology, Pittsburgh, gives a half-year course or 1 year course. On 5 nights a week, 4 hours are devoted to lectures on equipment, gases, methods of welding various metals, and shop work and on oxy-acetylene welding and cutting. This course and No. 2 are given during the first or second semester. Similar periods are given to electric-arc welding, and lectures cover equipment, bare, flux-coated, and shielded arc electrodes, and the welding of various metals. Carnegie has a spacious and well-equipped laboratory. Shop work consists of welding steel in horizontal, vertical, and overhead positions. The tuition fee for each of these four courses is $24 per semester. The Department of Metallurgical Engineering lectures on welding metallurgy - the production and working of metals and alloys, properties of metals and alloys, welding methods, and weldability of metals. This is a one-semester course with a tuition fee of $9.

In the Mechanical Engineering building, Colorado State College, Fort Collins, Colo., forging and welding include the working of iron and steel at the forge and oxy-acetylene and electric-arc welding, both for farm requirements.

The workshop of the College of Engineering, University of Colorado, Boulder, Colo., can accommodate 20 students at each session. The equipment includes oxy-acetylene welding apparatus, a Lincoln shielded arc-welder, an Omaha electric welder, and accessory tools for welding, forging, and tool-dressing.

Instruction in the forge shop of the Department of Mechanical Engineering, University of Idaho, Moscow, Idaho, includes oxy-acetylene welding.

One of the cooperative investigations of the University of Illinois, Urbana, Ill., listed in the annual register for 1936-37, was on rigid welded joints with the Research Committee of the Chicago Section of the American Welding Society. This study was being made in the Engineering Experiment Station.

A gas and electric welding course is given by the International Correspondence Schools, Scranton, Pa. This comes under the "School" of Mechanical Engineering. The subjects taught include arithmetic, elementary chemistry, metallurgy of ferrous and nonferrous metals and fuels, welding equipment for all purposes, and all methods of welding.

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The engineering course in the University of Maryland, College Park, includes lectures on welding and laboratory practice.

Massachusetts Institute of Technology, Cambridge, has an advanced course in welding engineering for students who expect to be actively engaged therein. Metallography of welded joints is studied.

Forging, shop heat-treating, and welding by gas and electric arc are assigned 6 hours of lecture and laboratory each week in the College of Engineering, Ohio State University, Columbus, Ohio.

The curriculum leading to the degree of B. S. in industrial education, College of Engineering, University of Oklahoma, Norman, Okla., includes a course in the welding of metals and alloys by the oxy-acetylene process. The fee is $10.

Two theses on welding are listed in the Bulletin (Library Studies 1, 1938) of Pennsylvania State College, State College, Pa.: One in 1922, by M. M. Babcock, An Investigation of Oxy-acetylene Welding of Steel Plates, for the degree of M. S., and one in 1932, by H. S. Anderson, A Study of the Metallography of Welding, for the degree of Met. E. The shops in the School of Engineering can deal with light forgings and gas and electric welding.

The equipment in the forging, heat-treating, and welding laboratory at Purdue University, Lafayette, Ind. includes an acetylene-gas generator and 26 gas-welding and cutting outfits, 11 electric-arc welding stations, 2 spot-welders, and 1 butt welder.

Polytechnic Institute of Brooklyn, N. Y., offers, in addition to the actual welding work given in the shop, a course entitled "Welding and Design". This consists of 45 hours in class and demonstrations of welding processes, also, in connection with the New York Section of the American Welding Society, a 10-session lecture course in the evening.

At Rensselaer Polytechnic Institute, Troy, N. Y., mechanical engineering undergraduate courses in elementary shop work include exercises involving upsetting, drawing, bending, and welding. In metallurgical engineering, the undergraduate courses include one on the theory of welding and laboratory work designed to familiarize students with welding methods and so make them able to select the best one for particular applications. The effect of welding heat in causing deflection and internal stresses and in changing strength, hardness, and grain structure is explained.

In Rutgers University, New Brunswick, N. J., undergraduates in mechanical engineering have recitations on and practice in elementary machine-shop work and welding.

The welding course at Utah State Agriculture College, Logan, Utah, costs $25. Gas and arc welding of all metals is taught and practised, as well as preheating and preparation of cylinder blocks and other castings.

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Shop facilities in the University of Utah, Salt Lake City, Utah, are complete for all types of welding.

The laboratory in manufacturing methods, University of Washington, Seattle, Wash., has three major divisions, welding and heat-treating being one. It has two electric-arc welding machines, a spot welder, oxy-acetylen welding and cutting equipment, and profile-cutting machine.

In addition to the foregoing instruction, Lincoln Electric Co., Cleveland, Ohio, well-known maker of welding appliances and publisher of bulletins and the Procedure Handbook of Arc Welding - Design and Practice (in its fifth edition, 1012 pages) encourages the study and operation by giving a 4-week free training course in welding at its plant in Cleveland and assists in the advanced course (fee, $10) given in the John Huntington Polytechnic Institute, Cleveland. Through the James F. Lincoln Arc Welding Foundation, this firm also offers liberal cash prizes for the best-written theses on welding.

Training in Britain and Europe

At the symposium on welding iron and steel in London in 1935, previously mentioned, the director of naval construction stated that far more attention was being given in England and abroad to the training of welders than formerly, when there was a tendency to assume that the actual operation of welding was a simple matter calling for little skill or training. The assumption that any man of average ability, after a few lessons in the handling of an electrode, will develop into a successful welder, is not justified by experience. A certain sense of touch is necessary, without which it is impossible to use an electrode properly.

W. Spraragen, previously cited, wrote on welding research in the United States at this symposium. He estimated that not more than a quarter of the possibilities of welding have been fully explored. This is not strange when one considers the complex metallurgical problems and the large number of variables generally involved. Good results in any specific case usually may be obtained in a variety of ways.

E. A. Atkins, also at the symposium, thought that there can be no doubt whatever that the chief factor in the production of high-class welded work is the welder. All the work of the designer, metallurgist, and plant engineer may be useless unless the welder can be relied upon to produce work of the highest quality. Some welding jobs are simple, whereas other work demands the highest skill resulting from long training and experience. Many welding classes are held in technical schools, colleges, and workshops, but this short training is only groundwork, which must be supplemented by good shop experience. The best welders usually are men recruited from the various metal-working trades.

D. H. Ingall and D. D. Stockley, Borough Polytechnic, believe that the function of a technical institution is to serve industry. Because of the great expansion in welding there is a dearth of well-trained men. Full-

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time day courses and part-time evening courses are given in Great Britain but these should be developed further. A central school of welding, completely equipped, was proposed.

In Europe, Ingall and Stockley said the system of training reflects the ideas of industry, which more or less finances the schools. The methods adopted vary, but many commence with boys at the age of about 13, and the training constitutes essentially an apprenticeship for the trade. The objective appears to be to produce good tradesmen or foremen and not merely operatives suited for a certain type of machine.

ADDENDUM

Soon after this review on Minerals Used in Welding had been completed, the authors read an expertly written and concise article on the subject by Andrews,[31] an English metallurgist, and felt that it should receive special mention, even to recommend it as instruction in classes on welding.

To simplify the approach to the subject, Andrews confines his article to the arc-welding of mild steel and to classify broadly the types of electrode available. He considers it rather surprising that some degree of standardization of the types of flux coating used has not yet been developed. Manufacturers of electrodes offer the welding industry a large variety of products, and the range appears to be expanding, rather than contracting, into a number of recognized types. The reasons for this lie partly with the inspection authorities (British), partly with the users of electrodes, and partly with the manufacturers. Many outdated types of electrode often remain in use and continue to be manufactured.

Andrews states that the classification of fluxes is complicated by the necessity for considering the methods of manufacture. Most modern fluxes consist of a mixture of minerals, chemicals, and alloys homogeneously bonded with an alkaline silicate solution. Subsequent drying gives a hard cement of reasonable permanence, though all fluxes suffer deterioration if stored for any length of time under excessively damp conditions, especially where the atmosphere contains, in addition, a high proportion of carbon dioxide.

The functions of flux coatings are discussed. The earliest fluxes were much simpler than those in general use today and often consisted of simple iron oxide-silicate mixtures, as occur in blue asbestos and are employed extensively now. The general principles of electrode-flux compositions are fairly well known; and in most mild-steel electrodes they usually consist of mixtures of mineral silicates, ferroalloys, metallic oxides, fluorides, and carbonates, together with organic compounds, apart from those used to assist extrusion in the making of electrodes, which process is briefly explained with the use and reactions of binding agents. The materials should be plentiful and reasonably cheap, so that natural minerals, rather than prepared chemicals, will be used more commonly.

31/ Andrews, W., Some Observations on Metallic Arc Fluxes: Engineer, London, vol. 169, March 8, 1940, pp. 224-226.

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Andrews then gives some description of the materials most commonly employed - minerals, ferro-alloys, carbonates, oxides, and organic products. Two main divisions of electrode coatings must be recognized - arc stabilizers and true fluxes. The former is an ultra thin wash. True fluxes may be divided into slag-shielded types and gas-shielded types. A proposed classification of electrode manufacture lists them, with details of processing, under dipped process, wrapped process, wound extruded, and plain extruded. Then are listed the types of flux coating to be employed - for arc stabilizers, carbonates, titanium dioxide, and similar materials; for slag-shielded types, iron oxide-silica and iron oxide-silicon alloy, titanium oxide-alloy, titanium oxide-silicon alloy, and fluorides and other chemicals; for gas-shielded types, with an organic material of the cellulose class, may be an iron oxide-silicon alloy, a titanium oxide-alloy, or a titanium oxide-silicon alloy.

Andrews hopes that this classification of types of fluxes will be considered by the appropriate authorities and some standard be proposed that will reduce the very wide variety at present available.

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